AFHRL-TR-87-34 SEP 1988 421-E-3 D 301 45 27:87-34

AIR FORCE HUMAN RESOURCES LABORATORY

MODERN TRAINING MODEL CONCEPTS FOR AIRCREW TRAINING

J.M. Ryder
R.G. Beckchi
R.E. Redding

Pacer Systems, Incorporated
4 Horsham Business Center
300 Welsh Road
Horsham, Pennsylvania 19044

Bernell J. Edwards

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85240-6457

June 1988
Final Report for Period September 1986 - May 1987

Distribution authorized to DOD components only (Proprietary Information, June 1988). Other requests for this document shall be referred to AFHRL/TSR, Brooks Air Force Base, Texas 78235-5601.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5601

COMPLETED

BEST COPY AVAILABLE

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Distribution authorized to DoD components only (Proprietary Information, June 1988). Other requests for this document shall be referred to AFHRL/TSR, Brooks Air Force Base, Texas 78235-5601.

This report has been reviewed and is approved for publication.

HAROLD G. JENSEN, Colonel, USAF
Commander

WARNING - This document contains technical data whose export is restricted by the Arms Export Control Act (Title 22, U.S.C., Sec 2751, et seq.) or The Export Administration Act of 1979, as amended. Title 50, U.S.C., App. 2401, et seq. Violations of these export laws are subject to severe criminal penalties. Disseminate in accordance with the provisions of AFR 80-34.

DESTRUCTION NOTICE - For classified documents follow the procedures in DOD Manual 5200.22, Industrial Security Manual, Section II-19, or DOD Regulation 5200.1 AFR 205-1, Information Security Program, chapter IX. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution authorized to DOD components only (Proprietary Information, June 1988).
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFHRL-TR-87-34
6a. NAME OF PERFORMING ORGANIZATION Pacer Systems Incorporated 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Operations Training Division
6c. ADDRESS (City, State, and ZIP Code) 4 Horsham Business Center 300 Welsh Road Horsham, Pennsylvania 19044	7b. ADDRESS (City, State, and ZIP Code) Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85240-5457
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Human Resources Laboratory 8b. OFFICE SYMBOL (If applicable) HQ AFHRL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-86-C-0017
8c. ADDRESS (City, State, and ZIP Code) Brooks Air Force Base, Texas 78235-5601	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 62205F; PROJECT NO: 1123; TASK NO: 37; WORK UNIT ACCESSION NO: 15
11. TITLE (Include Security Classification) Modern Training Model Concepts for Aircrew Training	
12. PERSONAL AUTHOR(S) Ryder, J.M.; Beckchi, R.G.; Redding, R.E.; Edwards, B.J.	
13a. TYPE OF REPORT Final 13b. TIME COVERED FROM Sep 86 TO May 87	14. DATE OF REPORT (Year, Month, Day) June 1988 15. PAGE COUNT 50
16. SUPPLEMENTARY NOTATION This report documents Phase I of a Small Business Innovative Research effort. This report may not be released outside the DOD, without contractor permission, prior to May 1990.	

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	aircrew training	instructional technology
05	08		cognition	skill acquisition
05	08		instructional design	task analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This Phase I Small Business Innovative Research (SBIR) project reviewed recent work in cognitive science and instructional technology to provide a foundation for developing cognitive-based instruction for aircrew training in the Air Force. Advances in cognitive science provide new ways of characterizing learning and skill development that are more appropriate for the complex tasks requiring training today than are the behavioral constructs on which existing Instructional Systems Development (ISD) procedures were based. The areas of research investigated include knowledge representation, skill acquisition, automaticity, metacognition, cognitive task analysis, and cognitive instructional technologies. It was concluded that ISD remains a viable methodology if procedures are incorporated for addressing skills that are primarily cognitive in nature. Specific suggestions for the analysis and design phases of ISD are made.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Nancy J. Allin, Chief, STINFO Office	22b. TELEPHONE (Include Area Code) (512) 536-3877 22c. OFFICE SYMBOL AFHRL/TSR

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

SUMMARY

This report documents the investigation of conceptual and theoretical areas of cognitive psychology as possible means for improving the process of Air Force aircrew training analysis and design. Specifically, this research examined the application of cognitive task analysis as a means for identifying and defining design approaches to the training of electronic warfare officers (EWOs) of the Military Airlift Command. As detailed in the report, several areas of cognitive psychology may afford useful approaches to the improvement of the training analysis and design process. In the present report, theoretical areas were examined for application to the tasking of MC-130E EWOs. General approaches to task analysis and specific implications for training program development are discussed in the report.

PREFACE

This effort represents a portion of the research and development (R&D) program of the Air Force Human Resources Laboratory (AFHRL) for Technical Planning Objective 3, the thrust of which is aircrew training development. The general objective of the thrust is to identify and demonstrate cost effectiveness in training Air Force aircrew members. The present effort was conducted as a part of Work Unit 1123-37-15, Modern Training Model Concepts, under Contract No. F33615-86-C-0017, Small Business Innovative Research (SBIR) Project Number FY8993-86-01055. The research was accomplished in cooperation with the Military Airlift Command (MAC) in accordance with terms of a Memorandum of Agreement (MOA) between Hq MAC/DOT and AFHRL. The purpose of the present effort was to explore methodology for improving the process of planning and designing training programs.

The authors gratefully acknowledge the support efforts of MAC personnel who made possible the collection of field data required for the task analysis accomplished as part of this effort, specifically Lt Col Art Rolling, Project Officer, HQ MAC/DOXT, and Lt Col Duane Barts, HQ First SOW/DOT, who coordinated the field visits, interview schedules, and furnished technical data required for this report.

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
1.1	Purpose	1
1.2	Background	1
1.2.1	New Requirements	1
1.2.2	Instructional Systems Development (ISD)	1
1.2.3	Theory and Application	1
1.3	Review Methodology	2
1.4	Report Organization	2
2.0	FOUNDATIONS OF COGNITIVE SCIENCE	2
2.1	Information Processing	2
2.2	Knowledge Representation	4
2.3	Skill Acquisition	6
2.4	Automatic Versus Controlled Information Processing	8
2.5	Metacognition	10
2.6	Individual Differences: Cognitive Styles	10
3.0	FOUNDATIONS IN INSTRUCTIONAL DESIGN TECHNOLOGY	11
3.1	Transition From a Behavior-Based Emphasis	12
3.2	Establishing Cognitive Approaches to Instruction	12
3.3	Impact of Technology on Cognitive Instructional Design	13
4.0	TEACHING PROBLEM-SOLVING AND METACOGNITIVE SKILLS	14
4.1	Teaching Problem-Solving Skills	14
4.2	Teaching Cognitive Learning Strategies	17
4.3	Facilitating Access and Transfer	18
4.4	Teaching Self-Monitoring and Self-Regulation	19
4.5	Teaching Effective Decision Making	19
4.6	The Role of Metacognitive Training in Relation to Problem-Specific Training	21
5.0	COGNITIVE TASK ANALYSIS	21
5.1	Definition of Cognitive Task Analysis	21
5.2	Methodologies	22
5.3	Issues	25
6.0	ELECTRONIC WARFARE TRAINING APPLICATION	25
6.1	Perceptual-Motor Training Activities	25
6.2	Decisional Activities	26

V

Table of Contents (Concluded)

Page

7.0 COGNITIVE-BASED INSTRUCTIONAL DESIGN 28

7.1 Analysis 28
7.2 Design 29

7.2.1 Developing Objectives 29
7.2.2 Developing Tests and Describing Entry Behavior 31
7.2.3 Determining Sequence and Structure 31

8.0 CONCLUSIONS 32

REFERENCES 34

APPENDIX A: PROPOSED FOLLOW-ON WORK 43

LIST OF FIGURES

Figure Page

1 Information Processing Model 3
2 Threat Analysis Elements 27

MODERN TRAINING MODEL CONCEPTS FOR AIRCREW TRAINING

1.0 INTRODUCTION

1.1 Purpose

This report addresses the Air Force need for an improved conceptual framework to guide the design of aircrew training programs and the application of training devices. Recent work in cognitive science and instructional technology is reviewed and integrated to provide a foundation for developing a cognitive-based approach to instructional design. A description of how such an approach might be applied to a "real-world" training problem is contained in Section 6.0 of this report.

1.2 Background

1.2.1 New Requirements

Increases in the power and sophistication of modern combat aircraft require pilots to develop highly specialized performance proficiencies. Roscoe, Jensen, and Gawron (1980) have described an array of activities performed by pilots including procedural, perceptual-motor, and decisional tasks. Aircraft complexity in avionics, sensor, and other subsystems--in addition to the demands of the combat mission--make cognitive workload clearly the most critical area of aircrew readiness training. Yet, current training design procedures offer few insights or guidelines for addressing the training of complex cognitive skills. It seems appropriate, therefore, to examine recent research in cognitive science as it may relate to improvements in the training analysis and design process.

1.2.2 Instructional Systems Development (ISD)

Instructional Systems Development (ISD), as documented in Air Force Manual 50-2 and Air Force Pamphlet 50-58, provides a holistic, systematized approach to training analysis, design and development. It has been applied successfully for training programs emphasizing procedural and psychomotor tasks. Halff, Hollan, and Hutchins (1986) found ISD procedures were most easily applied to training tasks having a high ratio of overt behavioral skills to cognitive skills. One reason for this finding is that the theoretical base for ISD is behavioral in nature, and the instructional paradigm, developed in the early 1970's has not been modified to incorporate more recent research in cognitive psychology. Although ISD methodology remains a useful approach in many respects, the present report is intended as a survey of cognitive research, with a view toward possible enhancement of the ISD process.

1.2.3 Theory and Application

Tuthill and Ashton (1983) have advocated deliberate dialogue between scientists and practitioners to shorten the process of transitioning psychological theory to applied training practices. Others (including Snelbecker, 1985) have cautioned that attempting to rush or force the transition process is a disservice to both the scientist and the practitioner. As a possible solution, Glaser (1976) has suggested a linking process as a bridge between emerging scientific theory and application.

In Glaser's terms, the bridge turns out to be a science of training design, also known variously as educational technology, instructional science and/or technology, and performance technology. Though instructional technology is beginning to exhibit a level of scientific rigor comparable to that of other psychology disciplines, Gallini and Fisk (1986) have noted a lack of dialogue between instructional technology and psychology, leaving many unanswered questions about transitioning theory--particular in such areas as cognitive skills development--to applied training practices. As related to the training of aircrews, it is this issue which prompts the preparation of the present report.

1.3 Review Methodology

This report provides a review of recent literature in cognitive science relative to instructional analysis and design, with a view toward identifying improved linkages between cognitive science and instructional technology. The review builds upon the work of Spears (1983), who provided an assessment of cognitive approaches to training design, and the work of Knerr, Morrison, Mumaw, Stein, Sticha, Hoffman, Buede, and Holding (1986), who examined cognitive analysis techniques applied to a methodology of aircrew part-task training. The primary sources for the present review were documented since 1980, although a few earlier articles were included because of their particular relevance.

1.4 Report Organization

Chapters 2 and 3 of this report present findings from the two major areas of literature reviewed: cognitive science and instructional design. Each section mentions theories, approaches, and concepts developed by researchers, practitioners, and technologists that address germane issues. This review also suggests cognitive approaches to training needed to deal with general and domain-specific cognitive skills. Chapter 4 reviews methods for teaching general cognitive skills. Chapter 5 reviews some recent attempts to analyze tasks to identify cognitive components and discusses methodologies for analyzing domain-specific knowledge and skills. Chapter 6 describes the application of cognitive techniques to the development of training for Air Force electronic warfare officers in certain types of aircrew tasks. Emphasis is upon cognitive skills such as decision making for dealing with threats. Chapter 7 presents a framework for cognitive-based instructional design, suggesting how this framework might be integrated with the present ISD model.

2.0 FOUNDATIONS OF COGNITIVE SCIENCE

Research on cognitive processes is generally considered to have developed rapidly after about 1960. In surveying these developments, Mayer (1981) indicated several significant influences contributing to the rise of cognitive science; such influences include the introduction of the computer, the psycholinguistic work of Chomsky (1957), and the psychobiological contributions of Piaget (1954). Since these developments, cognitive psychology continues to evolve, probing a broadening range of human mental activities. Areas of cognitive science which appear of greatest relevance to the development of approaches to aircrew training are treated in the present chapter.

2.1 Information Processing

Research in cognitive science, and particularly cognitive psychology, is based upon the premise that humans are active, goal-oriented information processors. This contrasts with behavioral psychology, which is concerned only with overt behavior. Cognitive science focuses upon the mental processes which are considered to underlie behavior.

This chapter introduces a generalized model of human information processing and some assumptions concerning this model which may bear upon the design of aircrew training programs. The basic components of the information processing model (adapted from Wickens, 1984) are shown in Figure 1. These are represented as a composite of processing mechanisms that operate on information from the environment, interact with stored knowledge sources (memory), and result in overt actions (behavior). The boxes denote mental processes or structures which store or transform information. Although arrows indicate direction of information flow, the model does not imply a strictly serial sequence of events. Some processes (e.g., sensory processing) operate automatically without conscious attention; however, most are under conscious control and require processing resources (attention) for their operation (as shown by the arrows from the "attentional resources" bubble).

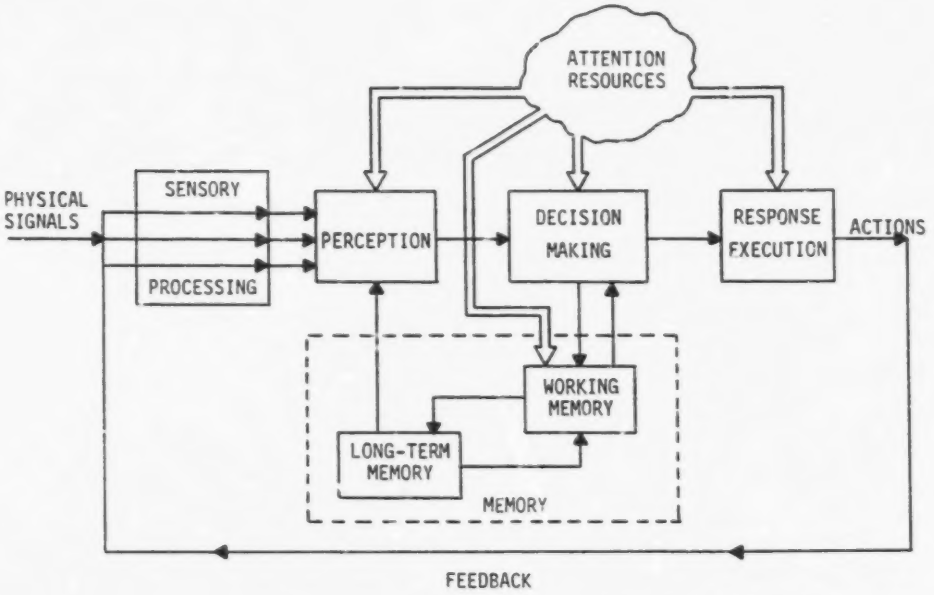

Figure 1. Information Processing Model.

The essential process shown in the model is as follows: Physical signals from the environment are received by the sensory systems and transduced into an internal (mental) representation. Perceptual processes then identify and categorize the sensory information in terms of past experiences (long-term memory). The next stage involves deciding what to do as a result of environmental events that have been perceived, current goals, existing context, etc. Finally, actions are executed by the motor control system. The feedback loop from motor control to sensory processing indicates that individuals monitor and continually adjust their actions based on feedback (as in continuous perceptual-motor tasks such as the control actions involved in piloting an aircraft).

Long-term memory contains stored knowledge of the environment, based on the individual's experience. Because a major concern of cognitive science has been the representation of knowledge in memory, this topic is treated in more detail in Section 2.2. Generally, long-term memory is a large-capacity store containing conceptual knowledge (i.e., facts about concepts and their interrelationships), procedural knowledge (i.e., knowledge about how to accomplish various mental or physical tasks), and episodic memory (i.e., a temporal record of events within personal experience). Working memory is a limited-capacity memory used to temporarily store data that are involved in ongoing mental operations. Attention is required to maintain data in working memory.

BEST COPY AVAILABLE

The decision-making process encompasses the bulk of complex mental processing. It includes memory processes such as search or interpretation of existing memories, construction of new memories and reorganization of memory, problem-solving processes such as hypothesis generation and evaluation, generation and monitoring of goals and plans, and response selection.

Another area of importance to aircrew training design is cognitive research on attention and processing capacity. An understanding of processing limits and bottlenecks may aid development of training methods which make the best use of limited attentional resources. Most processes require conscious attention to perform. However, skill automaticity, which is discussed in Section 2.4, appears to offer a potential means for freeing some aspects of attention during performance.

Within information processing theory, learning is viewed as changes in the content and structure of memory. In addition to initial knowledge acquisition, the kinds of processing that appear most important to skill development are: (a) reorganization of conceptual knowledge to be more hierarchical, more complete, and easier to access; and (b) development of procedural knowledge for task accomplishment. Because of the importance of skill acquisition for training, this topic is discussed in more detail in Section 2.3.

In addition to basic mental operations, humans have the ability to monitor and control their conscious cognitive processes to some extent. This ability, referred to in the literature as "metacognition," implies that individuals can learn to monitor and regulate their cognitive processes to facilitate performance of certain cognitive tasks. Further discussion of this topic is contained in Section 2.5.

2.2 Knowledge Representation

The complex tasks performed by pilots and aircrews require large amounts of technical knowledge. Crewmembers must develop and access large and accurate representations of knowledge related to the operation of aircraft systems and the performance of mission-related tasks. Understanding how knowledge is organized in memory, as well as the optimal conditions for acquiring and organizing information, is, perhaps, the key to understanding how to design and develop aircrew training programs.

The problem of how knowledge is represented in memory is one of the central issues of cognitive science. Much research in the past decade has dealt with the structure of memory, particularly semantic or conceptual memory. Within the field, there is some controversy as to the precise nature of representation (e.g., whether it is analogical or propositional) and as to the terminology used to refer to memory structures (e.g., semantic networks, chunks, schemata, frames, scripts). This review will focus on the common properties of cognitive models relevant to training.

In general, cognitive models of semantic memory (Anderson, 1976; Collins & Loftus, 1975) assume that concepts are linked together in a network, with the links representing the relationships between concepts. Some concepts are more closely linked than others, and the time required to activate the associations between two concepts is largely a function of the distance between the concepts (semantic distance). When a concept is activated or processed, activation spreads out along the paths of the network, but its strength decreases as it travels outward.

A cluster of knowledge representing a particular procedure, object, event or situation is referred to as a schema or frame. The recent work dealing with schemata (Bobrow & Norman, 1975; Minsky, 1975; Rumelhart & Norman, 1983, Rumelhart & Ortony, 1979, Thorndyke & Hayes-Roth, 1979) is important to training development. It provides a framework for improving techniques of

learning, skill acquisition and maintenance, and problem solving. Schemata have a number of properties that are relevant to training including concept abstraction, hierarchical organization, instantiation, induction, and prediction (Thorndyke & Yekovich, 1980). Each of these is discussed briefly below.

Schemata, as described by Thorndyke and Yekovich (1980), are "prototypical abstractions." That is, what is encoded in memory is a typical instance of a given concept, including the concept's essential features or attributes, its meaning, its uses, states or events in the environment associated with it, and other related schemata.

Secondly, schemata are hierarchically organized in memory. At the lower levels schemata are very specific or concrete, with the degree of abstraction increasing toward the upper levels of the hierarchical structure. For example, the concept for aircraft would contain generalized information characteristic of all aircraft; somewhat lower in the hierarchy there would be various classes of aircraft and, at yet a lower level, concrete instances or examples of specific aircraft.

A third characteristic of schemata, instantiation, implies that many properties of a schema are represented as unspecified variables that are specified, or instantiated, whenever the schema is used to organize incoming information. Other properties of the schema are fixed; that is, they are properties which pertain to all exemplars of the concept.

A fourth feature of schemata is that they are formed by induction from experience with various exemplars of the generic concept. As the individual accumulates experience with the concept, the schema is refined, in that the range of properties becomes more extensive and the range of the values of variables is more clearly defined.

A final feature of schemata is that their development includes the use of inferences in the form of predictions or expectancies which guide the interpretation and organization of incoming information. This aspect permits the process of reasoning (generalization from incomplete information).

A schema organizes new knowledge by assimilating it with previously structured knowledge. A schema also applies the knowledge and monitors its usage. Because schemata are organized around prototypes, predictions can be made regarding which new knowledge will be easiest to assimilate. New information which deviates widely from the prototypes already stored in memory will not be readily assimilated, if at all. Thus, as dynamic constructs, schemata are both data-driven (activated by environmental events) and conceptually driven (activated by the goals and expectations of the individual).

It has been argued that schema theory implies that increasing knowledge about a domain should cause increasing difficulty in information processing. The effect of an enlarged knowledge base, according to this argument, would be to increase search time, with more chance for error. However, such an effect has not been found. Smith, Adams, and Schorr (1978) investigated whether the integration of new knowledge would interfere with or aid processing of new bits of information within the network. They found when information was unrelated, individuals required more time to recognize an inferential statement if they had learned three facts rather than two. However, when the third fact was integrated with the first and second facts, there was no difference in recognition time between the two-fact and three-fact conditions. Thus, it appears integration of knowledge overcomes interference in the use of new information. This may be particularly important when the pace of learning is rapid (time-compressed tasks).

Schema theory has some general implications for the design and organization of training programs. A basic recommendation is that training-related information be structured such that new information is easily related to existing schemata (Bransford, Nitsch, & Franks, 1977). Morris and Rouse (1985) offered guidelines to facilitate this integration including: (a) organizing materials following a conceptual structure; (b) teaching prototypical concepts first, followed by variations; (c) teaching concepts, principles, and rules to supplement learning of facts; and (d) making materials more meaningful and related to real-world problems. Farr (1986) suggested instructional and learning activities be designed/organized such that the learner must actively process new information to enhance integration with existing schemata. Instructional methods to aid this processing would include elaboration and association techniques, advance organizers, formatting of written material, and mnemonic techniques (acronyms, visual imagery, etc.).

Memory schemata associated with a particular task or learning situation have been referred to as mental models. Such models can be simulated and used to represent how an individual conceptualizes a specific process, device, or system such as a radar system or aircraft. Mental models can also represent how an individual structures information about a particular task to be performed and methods of accomplishment. As an individual becomes more skilled in a particular task domain, his or her mental model evolves, becoming more efficient and flexible. Cognitive research in problem solving illustrates the significance of mental representation (models). Pelligrino (1985) found that the best problem-solvers are those who take the longest to mentally represent the "problem space" before attempting a solution. Rumelhart and Norman (1981) found the majority of errors in the learning of problem-solving tasks could be traced to faulty mental models.

Gagne and Glaser (1987) suggested four ways for encouraging the use of mental modeling as an aid to learning and performance: (a) build on common concepts and experiences individuals bring to a training situation which can be elaborated and refined as part of the training process; (b) use task analysis to identify how mental representation of task performance evolves from novice to expert stages, then use inferences from this analysis to sequence instruction about the task; (c) teach sound mental models of the task explicitly; and (d) identify models currently used by the learner and build on these by providing examples with which he/she can elaborate and test these models.

Models presented as part of instruction should clearly and succinctly represent task characteristics and constraints. Graphic representation of modeling processes such as Venn diagrams, maps, and flow charts has been found effective in making otherwise abstract modeling concepts, relationships, and processes more understandable (Hollan, Hutchins, & Weitzman, 1984; Rasmussen, 1986). Moreover, when teaching students to perform a task by focusing upon a mental model as a learning technique, the instructor should ensure that the conditions necessary to the model's development are an integral part of the course. This might include, for example, providing continuous, individualized feedback on performance for task components, as well for as the total task, so that individuals can detect errors efficiently (Wetzel, Knoske, & Montague, 1983).

2.3 Skill Acquisition

From the point of view of cognitive psychology, skill development is the development of schemata (Rumelhart & Norman, 1981). Schema theory provides an important basis for the discussion of skill acquisition because it helps to explain the organization and representation of old knowledge and the integration of new knowledge.

Because incoming knowledge can be received and integrated only in terms of prior knowledge, existing schemata influence new knowledge assimilation. Research indicates the ability to draw

inferences and to generate new knowledge is aided by ensuring optimal integration with schemata, which can be re-structured and refined (Norman, Gentner, & Stevens, 1976). From this view, schemata act as "scaffolding" by providing an organizational framework for instantiating new skill-relevant information.

Anderson's (1981) model of skill acquisition includes three phases of development. The declarative stage begins the skill acquisition process with the encoding of new skills as verbal knowledge within semantic networks. The second stage, knowledge compilation, has two substages: proceduralization and composition. Proceduralization is another term for the development of automaticity (discussed below); composition is the process of integrating knowledge in memory. The third, or procedural stage, is a process of refining the skill to fit a specific task or situation, and includes discrimination and/or generalization.

The major implication of schema theory and Anderson's skill development theory for training is that the training design should account for the representation of knowledge in determining how skills are learned. The accounting process should then be used to structure the training process to facilitate knowledge acquisition.

Rasmussen (1983) also distinguished three levels of behavior: (a) knowledge-, (b) rule-, and (c) skill-based performance. These correspond somewhat to Anderson's three phases of skill learning. During unfamiliar situations in which no rules for environmental control are available from previous experience, performance is knowledge-based. In such cases, goals are formulated explicitly, based upon analysis of the environment; then, alternative plans for goal accomplishment are developed and evaluated, and a plan is selected. Knowledge is defined as mental or conceptual models that support functional reasoning. Rule-based behavior involves the composition of a sequence of skilled routines controlled by stored rules or procedures that may have been empirically derived during previous occasions, learned from written or verbal instructions, or developed through conscious problem solving and planning. The performance level is goal-oriented and requires functional understanding of the environmental situation. Skill-based performance represents smooth, automated, and highly integrated patterns of behavior in which sensory inputs act as time-space signals that update and orient internal models. These types of behavior take place without conscious control, except for an intention to perform the activity.

According to Rasmussen (1986), activities are initially controlled by knowledge of both the structure and functioning of the immediate task environment. Initially, the activity is controlled by separate cues that are defined individually and related to rules controlling very elemental acts. As the skill develops, cues of a more global sort are adopted, and rules relating to activity patterns rather than elemental action are applied. Ultimately, the whole task may become automatic and performed without conscious awareness. As the skill level increases, the amount of conscious attention required for performance decreases, and attention can be increasingly directed elsewhere. The "spare" capacity can be used to update and extend internal models of the task activity for specialized situations or deviations from normal (skill refinement).

The literature of developmental psychology contains extensive evidence of the development of knowledge bases in children for a variety of domains. This evidence is meaningful generally because of its relationship to adult learning. Much of the development is due not only to changes in basic abilities but also to changes in the knowledge base. That is, for purposes of future learning, the acquisition of knowledge is just as important as developmental changes in abilities or ways of thinking (Carey, 1986). Scholnick (1983) noted that the knowledge acquisition process in the child is similar to that in the adult who is acquiring expertise in a new domain. As experience accrues, more peripheral instances are added and more attributes noticed, and the class is refined by creating subcategories.

Learning to fly offers a good example of complex skill development. At first the student pilot must devote attention and effort to every movement or minor decision; thus, performance is slow and error-prone. Novices may have difficulty merely keeping the aircraft on the proper heading. They must also attend to other control aspects more or less simultaneously, which may be disconcerting. Initially, the mental time-sharing required to maintain the various components of control at desired parameters will likely exceed the attentional resources of the student. However, with practice, the student becomes able to allocate attention such that each aspect of control can be monitored, corrected, and integrated to maintain desired flight parameters. Eventually, long sequences of movements or cognitive processes are performed with decreasing effort. With sustained long-term practice, the pilot becomes expert and can fly complex aircraft maneuvers, even while performing other tasks simultaneously (Colle & DeMaio, 1978).

2.4 Automatic Versus Controlled Information Processing

When a task can be performed with such proficiency that it no longer requires the deliberate attention of the performer, it is sometimes said to have been "overlearned" or "automatized." The principal distinguishing characteristic of such performance appears to be automatic cognitive processing (Schneider, 1985). Automatic processing is a fast, parallel process, not limited by short-term memory, and requiring little effort or attention by the performer but requiring extensive and consistent training (practice) to develop. Training automatic component skills has been shown (Fisk, Ackerman, & Schneider, 1985) to speed processing by a factor of 100 and to reduce mental workload by 95%. Further, and very important to aircrew performance, automatic component skills appear to make cognitive processing resistant to stress and fatigue effects.

In contrast, controlled processes are those which remain under conscious control and require the allocation of effort and attention. As such, tasks requiring controlled processing can severely limit human performance, especially vigilance (Fisk, 1985; Fisk & Schneider, 1981). Because controlled processing requires attention and effort and is limited by short-term memory, it entails serial rather than parallel processing (Fisk & Schneider, 1981).

Skill automaticity occurs in two ways: either through hereditary predisposition or through learning and repeated practice. The encoding of frequency, spatial, and temporal information involved in performing some tasks is an automatic process that does not need to be learned (Hasher & Zachs, 1979). However, for most tasks, skill automaticity develops slowly and only after repeated, and often massive, amounts of practice over a relatively compressed time period (Fisk, 1985; Myers & Fisk, 1985). The benefits of achieving skill automaticity for many tasks are considerable, and include ease of performance, reliability of skills, and freeing of cognitive processing capacity such that other tasks can be performed simultaneously without interference. A salient difference between novice and expert problem-solvers is the degree of task automatization; experts can perform many aspects of problem-solving tasks automatically (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Training can be accomplished in ways that make tasks more amenable to the development of automaticity. A critical variable in training appears to be the manner in which stimuli are presented to the learner. Automatic processing is thought to develop only when a given stimulus is consistently and repeatedly paired with a specific response. This relationship between stimulus and response elements is called "consistent mapping." Automaticity is the result of repeated practice through habituation to a specific stimulus-response pattern (Fisk, 1985; Myers & Fisk, 1985). Task performance has been found to be a direct, multiplicative function of the "degree of consistency between a given stimulus and its associated response, and the amount of practice" (Schneider & Fisk, 1982, p. 165). Moreover, training should allow the student a fairly high success rate so as to aid habituation (Fisk, 1985; Fisk & Schneider, 1981; Myers & Fisk, 1985).

Some guidance is available from the literature on the identification of tasks (or task components) which are good candidates for automaticity training. The identification of tasks which contain consistently mapped components requires in-depth cognitive task analysis. The task analysis involves determination of points at which training time can be "time-compressed" and determination of how best to "chunk" consistent components (Myers & Fisk, 1985). Identification of task components which are controllable through automatic processing is somewhat more difficult. For example, if task A does not interfere with task B, this may mean either that task A or task B is automatic or that they are both automatic (Schneider & Fisk, 1982). Although it is generally assumed that automatic tasks do not interfere with other tasks, this may not always be the case (Fisk & Schneider, 1983; Schneider & Shiffrin, 1985; Shiffrin & Schneider, 1977). Further, tasks that may not be amenable to automatization include those which are particularly difficult or problematic even after practice, or which require highly variable responding. It is important during task analysis to consult those who are expert in performing the task. Experts can help identify those components (particularly in problem-solving tasks) which require conscious, controlled effort and attention for successful performance. Such components probably cannot be automatized, at least within the context of task structure (Myers & Fisk, 1985). If an expert cannot perform a component automatically, it is improbable that a novice can be trained to do so, even after extensive practice. Task components which involve controlled processing are those which (a) exhibit performance decrements under conditions of heavy workload or stress, (b) are performed much more efficiently by experts (as opposed to novices or those with limited experience), and/or (c) are clearly susceptible to interference from other tasks (Fisk, 1985; Hasher & Zachs, 1979). Tasks which must remain under controlled processing during performance, or which cannot be automatized, should not be presented in a repetitive manner (Fisk & Schneider, 1981). In fact, conditions desirable for automaticity are virtually the reverse of those for controlled processing. Continuous and repetitive controlled processing is taxing for the human information processing system, and results in lowered vigilance due to operator fatigue. Training of controlled processing tasks should be presented in a manner that allows the operator to shift attention between tasks periodically.

Skill automaticity for a task is developed through extensive practice and the schedule should be arranged over a relatively limited time period. The trainees must remain active participants during practice sessions, and the task should be easy enough relative to the skill level of learners that they can be consistently successful in performing it. Students should be trained under stress-free conditions. As Fisk and Schneider (1981) noted concerning an experiment in which novice air traffic controllers were trained to perform a signal detection task, training under normal conditions may be "one of the worst ways of training operators to maintain detection performance" (p. 749).

Although many military tasks are quite complex, it appears possible to isolate consistently mapped components using the techniques described above. However, a comprehensive, reliable methodology for component identification for varieties of tasks awaits considerable additional research. Some scientists are of the opinion that only relatively simple tasks can be automatized successfully through explicit training routines (Hirst, Spelker, Reeves, Caharach, & Neisser, 1980). However, more recent research (Warm, Dember, Lazetta, Bowers, & Lysaght, 1985) indicates that task complexity may not be a critical factor. It may be that complex tasks can be automatized if they are properly decomposed into components which can be individually taught, and if training places consistent response demands upon the trainee. In this regard, the instructor can play a significant role in pointing out task consistencies, and thus guiding the student to "tune-in" to them (Fisk & Schneider, 1981).

Because of the growing criticality of cognitive workload as a training problem in aircrew readiness, the automatization of skill components may hold potential training benefits. However, a number of issues must be resolved in order to assess the feasibility of skill automaticity training for aircrew applications. Research shows that massive amounts of practice are required

to automatize even small skill components. Sustaining attention in the student over the number of trials necessary to development of automaticity could present a problem. Effective motivational strategies would likely be required to sustain student attention "on task." Another concern is the identification of consistently mapped task components. More must be learned about the composition of skill components within various types of tasks, and how to identify and present them in useful training contexts. The proficiency of expert pilots and aircrew members indicates clearly that many skills eventually become automatized as skill repertoires. However, such automatic processing is the result of many flying hours; sometimes years of experience may be involved. A general goal of automaticity research for aircrew training would be to define the processes by which skill automaticity is achieved, then determine improved training methods by which the time required to achieve skill automatization can be foreshortened.

2.5 Metacognition

The study of metacognition involves the more global control mechanisms which guide thought processes. Metacognition deals with self-awareness of cognitive processes, the monitoring, and management (also referred to as "executive processes"). As researchers investigate the mechanisms of human thought (how people think), a question of growing interest is: How do people think about thinking? The study of metacognition is a fairly new area in cognitive science, and one with implications for aircrew training. For a comprehensive treatment of this research area, the reader is referred to Flavell (1979), who has written an excellent summary of the nature and theory of metacognition.

The understanding of how people develop metacognitive abilities, how these abilities are used, and the relationship of these abilities to individual differences is helpful to an understanding of problem solving and other learning tasks. Relative to the application of problem-solving skills, Gelman (1986) found among individuals greater variability in metacognitive abilities than in basic cognitive abilities. Differences in performance may depend heavily upon one's skills in self-monitoring. For the process of training, what is needed is a reliable methodology for development of metacognitive skills relative to specific types of tasks. Although practice and experience are major determinants of skill acquisition and performance (Chase & Simon, 1973), it is important to determine what types of practice and exposure to tasks are most beneficial (Bransford et al., 1977). Research and training experiments in which metacognitive skills were taught to trainees have produced encouraging results (Bereiter & Scardamalia, 1985; Flower & Hayes, 1980; Schoenfeld, 1982, 1983, 1985; Wong 1980, 1982; Wong & Swatsky, 1984). Training in basic "thinking" skills, relative to the task, has been shown to enhance overall performance, as well as transfer to similar tasks. Moreover, some experiments which were intended to produce transfer across tasks, but in which metacognitive skills were not explicitly taught, have been unsuccessful (Belmont & Butterfield, 1977). A promising aspect of metacognition instruction is that it can transform basic fact and recall-oriented activities into lessons involving thinking (Bransford, Sherwood, Nye, & Rieser, 1986).

2.6 Individual Differences: Cognitive Styles

Cognitive styles define consistent individual differences/preferences for receiving, processing, and organizing information. They appear to act as "high-level heuristics" for the individual (Messick, 1984). Several styles have been identified and the constructs developed represent a fairly substantial body of literature. Such constructs purport to measure styles along bipolar scales. Field independence-dependence, serial-holism, and reflectivity-impulsivity are three principal cognitive styles. For a comprehensive review of the literature, the reader is referred to Messick (1984), who provides a detailed theoretical treatment of individual differences in cognitive style and their relevance to the training process.

Cognitive style is thought to be a critical variable in determining individual performance across a wide variety of tasks (Messick, 1984; Redding, 1986). Redding (1986) found that cognitive style differences predicted differential performance in various knowledge domains. For example, cognitive style was found to be more predictive of performance in academic-related problem solving than were aptitude tests (Federico, 1983; Federico & Landis, 1979, 1980). Relative to aircrew experience, cognitive style has been found to be of significance. For example, field independence has been found to increase with pilot experience (Long, 1975). The relevance of field independence-dependence to Air Force personnel selection is also seen in the fact that the Air Force Officer Qualifying Test (AFOQT) includes the Embedded Figures Test, a well-known measure of field independence-dependence.

Cognitive styles appear to affect the performance of individuals by influencing the manner in which information is processed upon initial presentation. Preferred styles seem to guide the manner in which attentional resources are allocated and decision making is accomplished. Since some tasks are thought to be more amenable to certain cognitive styles, individual preferences for tasks appear to be a function of task structure.

Several research studies show the importance of matching characteristics of the learning environment with cognitive style. Morris and Rouse (1985) reported research in which an interaction was found between impulsivity-reflectivity and task type. Impulsive students (as opposed to reflective students) exhibited little performance improvement in learning a technical troubleshooting task. The impulsive style, characterized by quick, often inaccurate responding, appears to interfere with the development of skill automaticity. However, in many cases, it appears possible to modify training tasks such that cognitive style can be accommodated to facilitate learning. For example, Kiewra and Frank (1986) found that structural aids which serve to organize training material (advance organizers) aid learning and retention for field-dependent individuals, but not for field-independent individuals. This finding seems congruent with metacognitive training, which emphasizes matching the manner in which skills are taught with specific aspects of information processing within the individual. Thus, if certain training strategies are contrary to individual processing style, their use might be counterproductive. In this regard, Pask and Scott (1972) found that "matched" students learned effectively, whereas "mismatched" students did not and were able to retain hardly any "ungarbled" knowledge.

Other individual differences, such as intrinsic and extrinsic motivational variables, and dimensions of personality such as reactivity level, are known to interact with cognitive styles to influence performance on many types of tasks. Further research is required to determine the relevance of cognitive styles and individual differences to aircrew training issues. Sufficient research on interactions between such dimensions of individual differences and specific types of aircrew tasks could influence the process of personnel selection and the design and development of training programs.

3.0 FOUNDATIONS IN INSTRUCTIONAL DESIGN TECHNOLOGY

Advances in cognitive science provide a growing body of data suggesting new approaches to instruction. However, there is a need to transition this body of research from an explanatory, descriptive science to a prescriptive, normative science (Glaser, 1976), one which serves to link theory with practice.

Instructional design technology may serve as such a link. Reigeluth and Stein (1983) have described instructional design as "a body of knowledge that prescribes instructional actions to optimize desired instructional outcomes...." Whether one views instructional design as a process, or in terms of specific products, the primary concern is development of competence in

learners, such that they exhibit behaviors and cognitive structures that differentiate the novice from the competent performer (Glaser, 1976). However, instructional design as a scientific discipline is still young, immature, and perturbed by substantial theoretical disagreement.

3.1 Transition From a Behavior-Based Emphasis

The literature of instructional design bears a preponderantly behavioristic theoretical base. From the cognitive viewpoint, this approach ignores internal mediation processes which occur during learning, in favor of focusing primarily upon the product (behavior) of an input-output model (Romiszowski, 1981). For many training designers, the instructional emphasis upon explicit behavioral objectives as end products of the process is correctly placed. Military and industrial applications of the behavioral approach have been generally well received because of the emphasis on utilitarian performance outcomes. This has been the case particularly for tasks involving basic perceptual-motor, procedural, rule-based, and knowledge recall skills.

The development of an engineering approach to training in the 1970's provided the logic for a systems approach to training development. The documentation of this process was formalized in a series of military publications which were adopted by all branches of the Armed Forces to provide assistance to instructional developers. The Handbook for Designers of Instructional Systems (AFP 50-58) is one such publication used by the Air Force.

A number of instructional design models currently in use by the industrial sector reflect substantially the same behavioral theory, practice, and procedures represented in military publications dealing with the ISD process. Nearly all variations of the ISD model include some version of the following developmental stages: (a) analysis (including task analysis), (b) design, (c) development, (d) implementation, and (e) evaluation. Elaboration of these procedures offers a standardized, generic framework to the training developer in approaching the task of developing products ranging from individualized training materials to comprehensive curricula and training systems.

The foundation of ISD can be found in the work of those psychologists who attempted to apply theories of learning as theories for instruction. For example, Gagne (1970) developed an approach to instruction based upon the identification of eight basic types of learning, with elaboration of the specific conditions required to facilitate learning for each type (Snelbecker, 1985). Subsequently, Gagne (1977) identified five learning outcome categories and described what he called the internal and external conditions of learning related to each category. Three of the categories--intellectual skills (procedural knowledge), cognitive strategies (executive control processes), and verbal information (declarative knowledge)--were clearly within the cognitive domain. Motor skills were part of the psychomotor domain, and attitudes were part of the affective domain. It is clear Gagne recognized a higher order of learning extending beyond the limits of the typical ISD model into the cognitive domain. Gagne and Briggs (1974) further elaborated Gagne's five categories and prerequisites for learning; these elaborations serve as useful guides for instructional designers. Higher-order human cognitive processes relative to instructional theory were recognized prior to Gagne, of course. Bloom's (1956) taxonomy of educational objectives for the cognitive domain described cognitive processes in terms of learning, but without the benefit of the prescriptions offered by Gagne and Briggs.

3.2 Establishing Cognitive Approaches to Instruction

The critical stages of the ISD model which may benefit most from cognitive approaches are the analysis and design stages. Other stages within the ISD model appear to remain valid and useful in many respects, including development, implementation, and evaluation stages. The current

challenge in the application of cognitive psychology lies among several competing instructional design theories and models. The challenge arises from the fact that cognitive approaches remain essentially descriptive processes, while the pressing need is for extensions of theory sufficient to support prescriptive approaches to training analysis and design.

From a macro perspective, the Elaboration Theory of Instruction (Reigeluth & Stein, 1983) appears significant as a leading development toward cognitive-based instructional design. Prescriptive recommendations for training design growing out of this theory are based upon an analysis of knowledge structures and cognitive processes within the learner. The Elaboration Theory requires the use of another theory, the Component Display Theory (Merrill, 1983) to detail prescriptive information. Component Display Theory relies on the establishment of goals or objectives in two dimensions: (a) type of content, and (b) desired level of performance. Both theories represent an extension of Gagne's work.

The attractiveness of these theories is that they provide practical approaches for the designer to structure training programs, approaches which appear to take significant steps toward bridging the gap between theory and practice in cognitive-based instructional design. Component Display Theory is an integrated, prescriptive framework which incorporates components from cognitive researchers and theorists such as Bruner (1966) on alternative representations; Evans, Homme, and Glaser (1962) on rule-example (RULEG) procedures; and Landa (1974) on algorithmization. Significant as an application of Component Display Theory was the development of the Instructional Quality Inventory (IQI). This 3-year effort, based upon Component Display Theory, identified methods for evaluating instruction in terms of a number of variables within a range of instructional objectives. The IQI effort culminated in the production of a training analysis/evaluation manual (Merrill, Richards, Schmidt, & Wood, 1977) intended to improve the instructional design process. IQI was designed to supplement existing military ISD procedures and intended for application with cognitive as well as psychomotor types of training tasks (Montague, Ellis, & Wulfeck, 1983).

3.3 Impact of Technology on Cognitive Instructional Design

Undoubtedly, computer-based instructional systems have, since the introduction of computers in education during the 1960's, had a great impact on the development of training analysis and design processes. Over the past several years, significant advancements in both computer technology and instructional methods have made possible synergies such as interactive instructional concepts and courseware authoring tools. Many significant research and development milestones in this field have been achieved under military sponsorship. Data indicate that computer-based instruction (CBI), in comparison to conventional lecture-based academic instruction, can produce equivalent or superior student achievement, with a 32% time savings (Orlansky & String, 1979). Similar results have been reported for civilian applications of CBI (Kulik, Bangert, & Williams, 1983). Formats of CBI can be divided generally into two types: (a) computer-assisted instruction (CAI) including several instructional modes such as drill and practice, tutorial sequences, Socratic dialogue, simulations, and gaming; and (b) computer-managed instruction (CMI), which deals with the management of data and student records associated with the instructional process. The combination of CAI and CMI can be a powerful tool for facilitating and monitoring the learning process. The Instructional Support System (ISS), developed for the Training Systems Division of AFHRL, offers an excellent example of such a tool (McDonnell Douglas Astronautics Company, 1986). Recently, research on the development of intelligent CAI (ICAI) has emerged as an effort to apply expert systems technology to the CAI process. This has been viewed by some pychologists as a further complicating factor which points up the inadequacies of the theoretical, analytical, and design concepts of instruction. Too often the tendency has been to emphasize the capabilities of tools (media) rather than to emphasize the undergirding theoretical and design principles of instruction. In the enthusiasm

BEST COPY AVAILABLE

for new technology, many overlook the fact that the quality of instruction depends much more upon the design and content of instruction--what the medium delivers--than upon the medium itself (Hoko, 1986). Thus, developments in technology point out shortfalls in the analytical and design processes which, in turn, emphasize the need for additional research.

4.0 TEACHING PROBLEM-SOLVING AND METACOGNITIVE SKILLS

In current practice, training programs are developed with the goal of skill development for specific tasks. The development of problem solving using metacognitive strategies represents a new point of departure in training research. To a degree, the teaching of metacognitive skills to facilitate learning has been demonstrated. The interaction of problem-solving skills development with knowledge acquisition has been discussed by Glaser (1984). This chapter reviews some of the literature in this area.

4.1 Teaching Problem-Solving Skills

The development of improved methods for teaching problem solving has great potential for application to aircrew training. Almost all aspects of tasks performed during combat missions require substantial problem-solving skills. Emergency detection/analysis/procedures, electronic countermeasures, combat tactics, mission planning, and other tasks are all fertile areas for the application of advanced training approaches to enhance acquisition of problem-solving skills by aircrew members.

The body of research on human problem solving is substantial. The use of heuristics and strategies in problem solving, from novice to expert levels in particular knowledge domains, is well documented. Individual differences are known to interact with problem solving as a function of expertise, prior knowledge, and the degree to which the individual "internalizes" the task. The nature of problem solving, types of problems, and common difficulties encountered in problem solving and their implications for training are reviewed in this chapter.

Newell and Simon (1972) provided seminal work and a general analysis of the problem-solving process. When confronted with a problem, an individual's first task is to construct the problem space. The problem space is a mental representation of the boundaries or constraints of the problem. In general, individuals must decide what operations to use within these constraints in order to move from the initial state to the goal state. Operations are procedures or subgoals employed to achieve problem solution. Constructing a correct or efficient representation of the problem space is perhaps the most crucial step in the process. DeCorte and Verschaffel (1981) analyzed errors made by second-graders on mathematical problems. They found most errors were due to the learner's unfamiliarity with the problem as presented. Often, children did not know how to formulate the problem space appropriately for the problem, although they knew how to solve the same type of problem when it was represented in a different manner. "The primary purpose in problem solving should be to better represent the problem space to find representations within which the problems are easier to solve" (Minsky, 1975, p. 259). Thus, the objective is to formulate a plan of action which conceptualizes the problem broadly enough to present a suitable range of alternative paths toward a correct solution.

The structure of the human information processing system places constraints upon any individual's problem space representation. Short-term memory capacity and storage time necessarily limit the number of sequential operations and permutations that can be evaluated. Furthermore, the involvement of long-term memory in the process appears to limit the number of problem paths tried or previous solutions to similar problems which can be remembered and retrieved. Although the role of memory in problem solving requires substantial further research,

it seems certain that problem-space representation is the critical factor. Problem-solving improvement across trials depends more upon the initial planning (problem space representation) than upon memory of details (Reed & Johnson, 1977).

Greeno (1978) identified three basic types of problems and the difficulties most commonly associated with each. These problem types are: (a) arrangement, (b) inducing structure, and (c) transformation. Arrangement problems are those requiring a particular structural arrangement to solve. Performance on arrangement problems is influenced by the individual's ideation fluency. Ideation fluency is the ability to generate possible subgoals and problem paths, ability to retrieve prior solution patterns from long-term memory, and knowledge of the principles which constrain the search. Functional fixedness, a sort of rigidity due to the inability to see alternative uses for a particular problem path or subgoal, can impede problem solving that requires arrangement. Problems of inducing structure do not present the individual with the goal state; the problem is to ascertain what the goal state should be. For example, in problems such as analogies or series problems, the individual must discover the relationship among the elements of the problem in order to induce the goal state. Transformation problems are usually those most frequently encountered in "real-life" problem-solving situations. In transformation problems, one is presented with both the initial state and the goal state. The problem is to determine the sequence of operations required to achieve the desired goal. When solving transformation problems, individuals usually perform a means-end analysis of the problem space, resulting in the formulation of subgoals. Subgoal formulation can be a powerful heuristic in avoiding searching incorrect paths. A subgoal serves as a "landmark" to be reached as an intermediate problem state (or subgoal) to correctly solve the problem. Subgoals also aid memory and evaluation of hypotheses by breaking the problem down into more manageable units. However, the use of subgoals does have limitations and dangers, because, in some cases, the solution may require that one move farther away from the goal at some point in the process (Newell, Shaw, & Simon, 1985). Because subgoals are usually successive and closer approximations of the ultimate goal, they may not yield a solution to such problems.

As mentioned, striking differences in problem-solving styles have been found between experts and novices. Major differences appear to be in the formulation of the problem space. A good example was provided by Chi, Feltovich, and Glaser (1981). They examined the problem-solving styles of experts and novices in the solution of physics problems. Typically, novices quickly attacked the problem, trying various problem paths randomly until the correct solution was found. In contrast, expert physicists would begin first by reflecting upon the problem in order to construct a mental representation of it. In other words, the expert systematically probes the dimensions of the problem to ensure a proper conceptualization, and uses underlying principles to form hypotheses to be tested toward the solution. Hypothesis generation is in clusters, reflecting a well-organized underlying schema. The novice typically generates and tests problem paths haphazardly, and time intervals between hypotheses reflect randomness (Larkin, 1979). Thus, differences in problem-solving style are apparently attributable to differences in the knowledge bases of experts and novices.

Bernascoli (1987) suggested a key that enables an expert problem-solver to go beyond the information given in his or her schematic knowledge of a domain. It appears that he/she is able to restructure knowledge in a particular way; i.e., to develop particular schemata through experience in a domain. Thus, possibly even more important than the amount of knowledge stored is the manner in which it is organized. Bransford et al. (1977) believed the process of becoming an expert is essentially one of decontextualization. That is, the expert's knowledge is less context- or situation-specific in that he/she can generalize abstract principles in order to solve problems across a range of situations. Silver (1981) found that "good" problem-solvers form problem categories based on the problem structure rather than relying on superficial, contextual cues. Also, many processes which are automatic for the expert require considerable effort for the novice. Apparently, the expert has so internalized many of the principles of the

domain that he/she can apply them spontaneously as needed. DeGroot (1966) observed: "We know that increasing experience and knowledge in a specific field (chess, for instance) has the effect that things which at earlier stages had to be abstracted, or even inferred, are apt to be immediately perceived at later stages" (p. 34). Cognitive growth is a "remodeling of structure" (Bransford et al., 1977; Piaget, 1952), as well as simply the accumulation of knowledge and experience. Thus, although only experience can reduce differences between novices and experts, facilitating better organization and recall of knowledge can perhaps turn a poor novice problem-solver into a good novice problem-solver.

The goals of training in problem solving should be: (a) to facilitate the development of expertise in the problem domain, (b) to facilitate access to problem representations stored in long-term memory, and (c) to ensure the learner's knowledge remains "active" rather than "inert." These goals are all quite interrelated. For example, facilitating access is a way of ensuring that knowledge remains active.

The most effective way to make a "poor" novice problem-solver into a "good" novice problem-solver, and thereby facilitate development of expertise, is to teach the student problem-space representational skills. Problem-space representations are influenced by the instructions about the task at hand, prior experience with the same or similar tasks, and the heuristics and algorithms stored in long-term memory which generalize to the task. Task instructions can aid the problem-solving process by providing explicit heuristics and algorithms applicable for the particular situation. For maximal retention, training for problem-solving skills must be done in an explicit manner. There is considerable evidence regarding those techniques which are effective as well as those which are not. Ineffective techniques include the use of implicit cues or heuristics and the discovery approach which requires the learner to apply abstract and theoretical principles intuitively in a practice setting (Miller, 1975; Morris & Rouse, 1985; Perfutto, Bransford, & Franks, 1983). It has been found that students usually do not perceive the relationship between two very similar problem types, even for relatively easy problems, when students are of low ability or when training must be conducted over a fairly short period of time (Gick & Holyoak, 1980; Reed, Ernst, & Banerji, 1974).

Instructional methods which have been found effective in aiding problem solving are those which focus on development of sound problem-space representational skills:

1. Problem-space representation can be enhanced by providing "advance organizers" (Ausubel, 1960) prior to task presentation. As the term implies, such organizers are informational aids which help the student absorb, structure, and store new details about the task. For example, providing information about the major topics of a textbook prior to its reading was found to significantly increase comprehension of textbook content.

2. Knowledge should be provided in hierarchical structures which organize information around "problem types" (DeJong & Ferguson-Hessler, 1986). Hierarchical organization is one of the most powerful heuristics for problem solving. The human information-processing system is organized in such a fashion, and concepts are stored hierarchically in memory. Information is organized in terms of subordinate, basic-level, and superordinate concepts, for example "collie," "dog," "animal." Basic-level concepts are thought to provide the most relevant information in the most efficient manner (Rosch & Mervis, 1975; Rosch, Mervis, Gray, Johnson, & Boyes-Braen, 1976).

Substantial evidence suggests children learn basic-level concepts first and with greatest ease (Horton & Markman, 1980; Mervis & Crisafi, 1982; Mervis & Pani, 1980). It may follow then, that adults learn new information when it is presented at some "optimal level" of organization equivalent or analogous to the basic level. Information for the adult learner probably should be neither too specific nor too general and should reflect similar hierarchical organization; that

is, the central concept should be interrelated with more specific concepts as well as with the more global or superordinate principles.

3. Problem-solving training should be organized around problem types to facilitate schema organization and transfer. DeJong and Ferguson-Hessler (1986) differentiated "good" from "poor" novice problem-solvers on the basis of the way their knowledge for the problem was represented in memory. "Good" novices more closely approximated the expert in that they represented the problems according to types, based upon underlying principles or "deep structures," and reflected a more systematic organization than that of the "poor" novices, who attended only to superficial problem characteristics.

4. In some instances, providing subgoals to the student may be helpful. A cognitive-based task analysis must be performed by the trainer to identify components of the task which would serve as useful subgoals for the student. Subgoals should be carefully selected and validated to ensure they actually facilitate end-goal problem solving.

5. In sequencing instruction of problem-solving steps, the instructor should guide the student by shifting to new problem states or subgoals rather than regressing to previous subgoals (Atwood & Polson, 1976).

6. Instruction by way of analogy to similar problems can be effective, if the analogy is simple and explicit (Reed et al., 1974).

7. Flexibility in problem solving should be taught so as to avoid problems with functional fixedness or negative set, thereby encouraging active student participation, questioning, and experimentation. Students should understand that different problem situations will likely require adaptability and modification of prior schemata and heuristics.

The most important consideration in teaching problem-solving skills and heuristics is that strategies must be taught explicitly. The instructor must communicate the importance of strategies and when, where, and how they are to be applied. Training which treats heuristics, but not their application or importance, is largely ineffectual in facilitating transfer (Brown, Campione, & Day, 1981). At the same time, however, the importance of heuristics should not be overemphasized, because over-reliance on them can lead to inflexibility and error-prone decision making.

4.2 Teaching Cognitive Learning Strategies

Cognitive learning strategies involve control of the processes of attending, perceiving, encoding, and recalling information. Recent research has shown such strategies can enhance learning (Anderson, Spiro, & Montague, 1977; O'Neil, 1978; O'Neil & Spielberger, 1979; see also Derry and Murphy (1986) for a comprehensive review of research on training in learning ability).

Dansereau (1978) designed a program to teach college students cognitive strategies for learning and retention. This program demonstrated the training effectiveness of both primary and support strategies. Primary strategies included comprehension and retention strategies (paraphrasing, forming mental images, and identifying important concepts and their interrelationships), as well as retrieval and utilization strategies (question decomposition and use of contextual cues). Support strategies included goal setting and scheduling, concentration and coping with distractions, and monitoring the progress of learning.

Weinstein, Underwood, Wicker, and Cubberly (1979) suggested that explicit training in the use of a variety of strategies is necessary to enable students to deal successfully with a range and

variety of tasks and to enable generation of novel strategies. Instructional design for problem solving should include strategy training. The structure and presentation of learning materials can reinforce the acquisition of strategies.

4.3 Facilitating Access and Transfer

Requisite knowledge to perform a task or solve a problem does not always ensure effective performance. Access to relevant knowledge from long-term memory is aided when the individual has so internalized the knowledge that the appropriate schema is "active" rather than "inert." Facilitating access also aids transfer and generalization to other tasks/situations; inert knowledge is accessed only in restricted contexts even though it may be applicable to a wide range of domains (Bransford et al., 1986). Bransford et al. (1986) cited a large body of literature suggesting that useful knowledge often remains inert and is not put to use in the problem-solving sense. Hence, the problem of access and transfer can be a serious one.

Furthermore, studies have demonstrated that individuals can have extreme difficulty in generalizing knowledge across similar problem types or isomorphs (Hayes & Simon, 1976). As Schoenfeld (1979) and others (Brown et al., 1981; Gick & Holyoak, 1980) have found, simply having knowledge of a strategy or heuristic does not necessarily mean that the individual will use it; in other words, it may be a question of performance rather than competence. Inert knowledge results when instruction entails learning the facts (or heuristics), but not their practical value and how and where they can be applied. Bransford et al. (1986) and diSessa (1982) argued that when students fail to learn how their "formal knowledge" can be applied, the result is a theoretical or laboratory-based understanding of the problem type, with little practical transfer to real-life situations. Morris and Rouse (1985), in a review of numerous training studies, concluded that "instruction in theoretical principles is not an effective way to produce troubleshooters. Fundamental understanding has been shown to be useful for answering theoretical questions, but not for solving problems" (pp. 514-515). Shepherd, Marshall, Turner, and Duncan (1977) trained students by providing either theoretical training, problem-solving heuristics, or simply a description of the operating system. They found that the group given problem-solving heuristics outperformed both the theory-trained and no-training groups (who performed equally well) in all problem situations. Similarly, Miller (1975) found that students enrolled in a theory-based course were generally less successful troubleshooters than were those who received more "functional" training. Perfutto, Bransford, and Franks (1983) provided subjects with prior cues to help them solve problems, but did not encourage them to attend to or apply the cues; another group of subjects received no cues. Both groups performed equally poorly in solving problems.

Relating new knowledge to previous knowledge schemata promotes access by providing more associative links in memory between the concepts. To an extent, all new knowledge is evaluated in terms of old knowledge; it is accommodated into existing schemata and made meaningful through its interrelations with other knowledge (Bransford et al., 1977). Studies (Adams, Perfutto, Yearwood, Kasserman, Bransford, & Franks, 1985; Gick & Holyoak, 1980) have shown that access is facilitated when prior knowledge is called upon to aid in the understanding of new knowledge or problems. Specifically, the Adams et al. (1985) training program helped students perceive the utility of the new information in solving problems which were presented. Relating new knowledge to prior knowledge also greatly enhances transfer (Norman, Gentner, & Stevens, 1976); diSessa (1982) advocated a "genetic task analysis" in which the goal is to identify components of prior knowledge or already-learned tasks for use in the learning of new knowledge.

A second way to enhance access and transfer is to help the trainee internalize or form a working model of the knowledge or operating system. This aids in both schemata formation and transfer. Eberts and Schneider (1985) pointed out that ability to correctly execute a skill does

not in itself mean that the individual has an accurate internal representation of the task. Unfortunately, not much is known about how to facilitate task internalization. However, several studies have indicated that actively visualizing the task (DeKleer & Brown, 1981; Eberts & Schneider, 1985; Mayer, 1981) and verbalizing task components (Bender, 1986) facilitates internalization through schemata formation.

4.4 Teaching Self-Monitoring and Self-Regulation

Perhaps one of the most important aspects of metacognition is the ability to monitor one's own skill when performing a task. Monitoring includes: (a) recognition of limitations in one's knowledge base or performance, (b) ability to accurately assess progress in task performance, (c) awareness of which task components remain to be performed, and (d) ability to modify one's behavior or schemata as required by task evolution. Lack of awareness of metacognitive processes is a common problem. Individuals commonly fail to recognize that they lack skills in problem solving or performing tasks (Bransford et al., 1986). Particularly, low aptitude learners or those with limited experience have difficulty recognizing when they have failed to learn or perform adequately.

In teaching metacognitive skills, the instructor should emphasize the applied aspects of metacognitive knowledge and processes. Students should understand why strategies are important and how the strategies can be applied to other similar tasks (Bernascoli, 1987; Bransford et al., 1986; Meichenbaum, 1985; Miller, 1975; Morris & Rouse, 1985; Perfutto et al., 1983; Shepherd et al., 1977). Providing such information helps the student gauge his/her progress and better understand the training process. Teaching self-regulatory and self-monitoring skills aids learning of specific skills and also appears to aid skill generalization to similar tasks (Scardamalia & Bereiter, 1985). Some research suggests that self-monitoring through verbalization of performance during the task aids skill acquisition and transfer (Bender, 1986).

Scardamalia and Bereiter (1985) developed techniques to aid development of problem-solving skills. Their efforts focused upon self-monitoring processes. First, those self-regulatory processes are identified which differentiate performance between novices and experts. An example of this process would be revision when writing. Once identified, self-regulatory components are explicitly, specifically, and concretely taught to students. For instance, revision in the writing process might be described by the subcomponents of "comparing, diagnosing, choosing a revision tactic, and generating alternatives" (Scardamalia & Bereiter, 1985). Knowing when to modify one's problem-solving routine to fit a particular task can be especially problematic, since people are usually much too conservative in revising their hypotheses and evaluating their own decisions (Collins & Smith, 1980; Edwards, 1968).

4.5 Teaching Effective Decision Making

Many of the principles found effective for teaching problem solving are equally effective in teaching decision making. However, in the case of complex decision making, the great amount of data that must be processed and evaluated by the decision-maker adds to the difficulty and complexity of applying the principles. Moreover, some efficient problem-solving heuristics are ineffective for complex decision making. An example is the so-called "availability heuristic" (Tversky & Kahnemann, 1973). This heuristic leads one to evaluate data primarily on the basis of the data's temporal priority or salience. That is, information which is most striking or recent is weighted most in the decision-making process, often without consideration of contrary evidence, even if such evidence is quite substantial. Another heuristic frequently used in evaluating information for problem solving is representativeness; i.e., evaluation based on the relative frequency of various types of information (Kahnemann & Tversky, 1972). The problem with

over-reliance on the representativeness heuristic in decision making is that the most frequently occurring data point is not necessarily always the correct one (Kahnemann & Tversky, 1972). Finally, people seldom revise their probability estimates when weighing incoming information. This results in overly conservative decisions (Edwards, 1968). People also tend to have a confirmatory bias--ignoring evidence which discredits their hypotheses, but favorably evaluating supportive evidence (Collins & Smith, 1980).

Elstein, Shulman, and Sprafka (1978) examined the decision making of medical students and found it quite inefficient and flawed. This finding led to a systematic analysis of the decision-making process, which resulted in the following recommendations for the use of decision-making heuristics when generating hypotheses, evaluating and gathering data, and making decisions (Reed, 1972):

1. Generating hypotheses:

   a. Avoid making snap decisions initially.

   b. Consider the most likely causes for the problem first.

   c. Consider initially those problems which are most readily solved and which also must be solved quickly.

2. Evaluating and gathering data:

   a. In troubleshooting or testing, consider both the probability and utility of the data. Tests should first evaluate the most common problems (probability), then those problems most in need of solution (utility).

   b. Perform a cost/benefit analysis of the troubleshooting procedure.

   c. Strive only for the degree of precision required for the problem.

3. Making the decision:

   a. Consciously try to avoid the tendency for a confirmatory bias. Evaluate data which invalidate the hypothesis as well as data which support it.

   b. Consider the possibility that the problem may have multiple causes, necessitating multiple decisions.

   c. Be willing to revise probability estimates as new data are obtained; do not be overly conservative in the decision-making process.

   d. In choosing between alternative solution paths, combine judgments of probability and utility to arrive at the best solution.

Decision making relative to aircrew training presents complex training design issues. Aircrew combat tactics training provides a good illustration. Beyond the development of a groundwork of explicit rules and procedures, there is a vast area characterized by higher-order skills (analysis, synthesis, and evaluation) for which explicit rules are not available. In such complex decision making, subjective judgments of experts, many of whom may disagree, may be the only information approaching performance criteria. Expertise in tactical decision making is the result of years of experience, and indeed, in the absence of actual combat conditions, there may be no fully adequate environment in which to develop some of the needed skills. As a practical

training consideration, what may be required is: (a) a basic decision-making skills training program which permits the student to acquire proficiencies for the explicit, rule-based skill portions of the tactical decision domain, followed by (b) a problem-generating practice environment (probably computer-based simulations) in which the student acquires advanced tactical decision-making skills through exposure to ascending levels of situational complexity. This latter training phase would provide extended training opportunities for the student to engage in as many relevant dimensions of combat tactics decision making as possible.

4.6 The Role of Metacognitive Training in Relation to Problem-Specific Training

What is known thus far from research indicates that providing explicit instruction on heuristics and strategies over a compressed time period will likely result in development of problem-solving skills at what might be called a basic level of proficiency. High levels of expertise or a highly developed theoretical understanding of a problem area is thought to be required when solving very complex problems, especially under unusual or novel conditions. Current understanding from the literature indicates such expertise is acquired only through extensive experience.

The teaching of cognitive skills emphasizes the value of self-discovery, insight, and creativity in the learning process. Such an approach teaches very general skills and an appreciation for learning, rather than a set of specific procedures or rules. This approach holds that the most effective way to learn cognitive and problem-solving skills is through experience. Thus, students are allowed to learn through their mistakes, since one learns as much from one's own errors as from direct instruction. Although this approach is time-consuming, it has been shown to produce students with a well-developed understanding of problem areas, experience which is transferable to other problem areas. The generalization of such experience acts to free the individual from control by specific stimuli (Gagne, 1965).

Providing explicit instruction in practical problem-solving skills is highly effective for the training of operators to perform routine tasks. However, the trainer should recognize that true expertise develops only as a result of much practical experience, in addition to formal training. The result is an intuitive and sophisticated knowledge base which is readily accessed, generalized, and applied. Finally, it should be recognized that although the development of metacognition and problem-solving skills can benefit the student, these skills do not compensate for individaul deficits in experience, education, ability, or motivation.

5.0 COGNITIVE TASK ANALYSIS

Primarily, it is the task analysis portion of the ISD process which should be modified to support training of cognitive skills. This chapter: (a) describes what cognitive analysis should entail, (b) reviews some recent efforts to perform this type of analysis, and (c) presents some of the research issues involved.

5.1 Definition of Cognitive Task Analysis

From the ISD perspective, task analysis involves examination of a given job (duties, tasks, subtasks, and activities) in order to identify the inputs, actions, and outputs required to perform the task or job. The process also includes identification of the conditions and proficiency requirements for each task component. Each component is evaluated to identify the desired behavioral response to be associated with corresponding stimulus aspects of the task.

From the viewpoint of cognitive psychology, such an analysis provides only a partial view of the task structure in that it omits accounting for the mental processes which mediate performance (Halff, Hollan, & Hutchins, 1986, p. 1132). From this viewpoint, behavioral analysis is neither efficient nor well suited for tasks composed predominantly of cognitive skills.

Cognitive task analysis views the operator as a goal-directed individual who performs certain mental operations (as well as overt behaviors) in order to successfully accomplish the task. The specific objective of analysis is to account for mental state changes during the performance of the task. Analysis identifies and describes: (a) the mental processes and skills required to complete the task, (b) when and how these skills are applied, and (c) how the limited resources of the information processing system can be allocated most efficiently during performance. A primary objective of cognitive analysis is to avoid "bottlenecks" in information processing required to perform the task. Specifically, the concern is with the process of skill acquisition; i.e., the manner in which a person develops expertise for the task. By examining the change in knowledge structures and mental processes as the individual advances from novice to expert, the analyst can gain insight into skill acquisition and how it can be improved. Glaser, Pelligrino, and Lesgold (1978) identified four steps in the analysis of cognitive skill acquisition: (a) analyze the knowledge structures of experts and novices, (b) determine intermediate states of knowledge between expert and novice levels, (c) specify the aptitudes required in the learner, and (d) specify the conditions which best facilitate progress from one knowledge state to the next.

5.2 Methodologies

Cognitive analysis should include: (a) the development of measurement instruments for assessing individual abilities as well as changes in the knowledge base; (b) the identification of task components; (c) the identification of the conceptual and procedural knowledge required for the task; and (d) the identification of differences between novices and experts.

In accomplishing these analytical steps, one should consider several methodological issues. The first of these is the sampling of the task domain. The paramount objective is to obtain data representative of the entire task domain and various operator ability levels. Analyzing only selected or limited aspects of tasks within a skill domain and/or analyzing the performance of operators of only one ability level can provide a limited and often misleading perception of task structure. Such biased sampling is unlikely to be an effective means to ascertain skill development. Analyzing task performance of operators of varying abilities provides insight into the development of expertise and the interaction between ability levels and task performance. Some analysts recommend a scalogram-type approach such that each level of skill required for a task is crossed with each level of operator ability in the analysis.

Another consideration is consultation with experts, both at the beginning and end of the task analysis process. The importance of comparing knowledge structures of experts and novices was discussed previously. The analyst should be aware that for many tasks, experts have refined performance to levels of skill automaticity; however, it is frequently difficult for experts to describe such automatic mental processes, although they can perform the skills exceedingly well. Further, experts may not have an appreciation for the range of abilities which various individuals bring to the task. Thus, the consultation of novices is also essential.

One of the most authoritative sources on cognitive-related task analysis is a report published by the University of Pittsburgh (Learning Research and Development Center [LRDC], 1986). This report recommends several general techniques to facilitate data collection from operators during task analysis:

1. Present experts and novices with hypothetical problem situations and ask them to "think aloud" (verbalize) while solving the problems.

2. Ask them to describe the procedures which they usually perform while completing the task.

3. Ask "metacognitive probe questions" while they are recalling the sequence of task procedures.

4. Use pictorial and/or verbal descriptions of concepts or tasks on cards. Ask operators to sort cards into piles in order to establish order or relatedness of concepts.

Perhaps the most important, yet difficult, aspect of cognitive task analysis is how to define and measure changes in the knowledge base as an individual progresses from novice to expert. This process is critical because the central purpose of analysis is to account for skill development through descriptions of mental processes. Several approaches to measurement of knowledge-base development have been reported in the literature. These techniques include procedures such as word association (Johnson, 1967) or Q-sort techniques in which the individual sorts concepts or task components according to his or her mental structure of the task (Shavelson & Stanton, 1975).

Naveh-Benjamin, McKeachie, Lin, and Tucker (1986) developed a method for defining and measuring changes in the knowledge base relative to skill acquisition. In pursuing this objective, they evaluated techniques from prior research in cognitive analysis. They found that most approaches have involved data transformations in which averaging techniques are used, causing representations of the linkages between concepts to be imprecise. Further, most methods have provided only static representations of the knowledge base, rather than dynamic representation of interactions within the knowledge base as it develops. Another limitation of this research is that analyses have been performed only on relatively small tasks during brief periods of learning.

Naveh-Benjamin et al. (1986) approached cognitive analysis with the objective of overcoming the limitations of earlier methodologies. The technique they developed, called the "ordered tree," assumes that individuals recall information serially, in chunks. In the ordered tree technique the amount of information which composes a chunk is inferred by inspecting groups of items that tend to co-occur in the subjects' descriptions of the task, or by observing their sorting of task concepts or components. An algorithm is then used to compute an ordered tree which provides a rich source of data about the individual's knowledge representation (schema) for the task or domain. The computed ordered tree reveals how information is organized, the nature and content of the information, the development of the hierarchy, the depth of organization, the similarity (or semantic distance) between concepts and structures, and the temporal priority of the information processed within each chunk. The priority, or order, can be unidirectional, bidirectional, or non-directional within the tree. Non-directional chunks of information occur together, but seem to have no sequence. Bidirectional chunks are characterized by the fact that the individual consistently processes first either the first or the last concept in the chunk. Concepts within unidirectional chunks are consistently processed in a particular sequence. The ordered tree technique differs from earlier procedures in that subjects are asked to sequence concepts presented on cards, rather than to recall concepts with verbal descriptions. This increases the directness, accuracy, and reliability of schema representation by placing less reliance on memory and verbal ability.

Naveh-Benjamin et al. (1986) used their ordered tree technique to examine student learning of a new knowledge domain. They compared the knowledge trees of three groups: poor students, good students, and experts (instructors). They discovered substantial differences in the number of chunks, and in the depth and order of knowledge structures among the three groups. The

ordered trees of instructors (compared to good students), and those of good students (compared to poor students), exhibited relatively greater overall organization, more unidirectional chunks, and greater depth of structure. As tracked by the ordered tree analysis throughout the learning process, concepts became more coherently organized and more elaborated (i.e., deeper hierarchical structures developed), and knowledge structures of students became gradually more similar to those of instructors. Knowledge became particularly more elaborated at the superordinate level of schema development. The Navch-Benjamin technique is useful beyond the static-only representation of the knowledge base in that analytical data are indicative of how the individual actually would use knowledge to perform the task. By extension, it is possible that this technique may enable prediction of the future direction of knowledge development within the individual. Naveh-Benjamin et al. speculated that perhaps the manner of processing information within chunks (directionality) might be used to predict the rate of learning progress for that chunk.

Another recent development in cognitive analysis is human performance modeling and simulation. Using computer-based techniques, this approach requires rigorous specification of task components. Knerr, Morrison, Mumaw, Sticha, Blacksten, and Harris (in preparation) have used such simulation modeling to analyze two aircrew training tasks: (a) 30-degree dive bomb delivery in the A-10 aircraft and (b) air-to-air radar intercept in the F-16A aircraft. Human performance models of these tasks were developed using micro-SAINT (Systems Analysis of Integrated Networks of Tasks), a software package specifically designed to model dynamic human operator-machine interaction. The micro-SAINT model of the air intercept task simulated the performance of an expert pilot by employing a rule-based model of the pilot's decision-making processes. Once the expert model had been validated, it was systematically degraded by omitting certain rules, to simulate the performance errors of inexperienced pilots. Continuing research with such modeling techniques may eventually prove useful as a tool for designing aircrew training programs.

Siegler's (1981) rule-assessment approach represents an interesting application of task analysis based upon literature in developmental psychology. He used in-depth analysis of rules and algorithms used by individuals to solve problems. The rules, as applied to different difficulty levels, were used to infer the conceptual theory guiding the problem-solving process. By constraining the possible solutions and tasks, Siegler could determine the missteps taken to arrive at incorrect solutions, and how many tasks (or at what level) one can correctly execute before errors (incorrect solutions) occur. A drawback with this method is that it is not easily adapted to multiple tasks with multiple components, which would seem to limit its utility for many applied situations.

Another issue to consider in cognitive task analysis is the identification of skills which students can learn to perform automatically (Myers & Fisk, 1985). As discussed in Section 2.4, this involves determining which components of a given task are consistently mapped. This differs from traditional (behavioral) task-analytic methods in that the component tasks may or may not be behavioral in nature.

Rasmussen (1986) presented a framework for cognitive task analysis derived from work in the process control environment. Four domains were identified for analysis of the decision-making process: (a) the problem domain, (b) the decision sequence, (c) the mental strategies for analysis, and (d) the cognitive control domain. Analysis of the problem domain involves representing the functional properties of the system to be operated. Next, the decision process is analyzed by representing a small number of typical decision sequences. Each representation shows information processing activities, resultant changes in knowledge states, and ways in which intermediate stages in the sequence can be bypassed as skill develops. The mental strategies and heuristics analysis examines required data and processing capacity for each phase of the decision sequence. The cognitive control domain analysis identifies whether the task performance is

skill-based, rule-based, or knowledge-based. The strength of Rasmussen's approach lies in the representation of the problem and decision sequence, not in the methods of deriving data.

5.3 Issues

Advances in the technology of cognitive task analysis represent substantial progress during recent years. However, a number of practical problems associated with these methods remain to be solved. Because of the complexity of obtaining and analyzing data effectively, cognitive analysis is not considered cost effective for applied purposes. Operations required to design measurement instruments, to obtain protocol data from expert and novice operators, and to analyze and interpret protocol data are highly specialized. For example, interpretation of results from the ordered tree method is time-consuming and requires trained analysts. Other approaches to analysis, such as computer-based modeling of human performance, are also labor-intensive at their present stage of development. Therefore, it seems evident that substantial future research will be required to advance these procedures to levels of practical efficiency for training analysis and design applications.

6.0 ELECTRONIC WARFARE TRAINING APPLICATION

Information in this chapter treats some aspects of the application of cognitive analysis procedures to a real-world Air Force aircrew training problem, the training of electronic warfare officers (EWOs). The job of the electronic warfare officer is to protect the aircraft from enemy threats by operation of specially designed electronic systems. The EWO may also deal with equipment limitations and failures as part of the process of identifying and dealing with enemy threats. From a behavioral perspective, much of the EWO's tasking consists of perceptual-motor and cognitive responses to the environment. Beyond the perceptual task aspects (interpreting information displays and other stimuli) which can be quite abstract and complex, cognitive workload can be very high, placing severe demands upon the operator's attentional resources. The principal procedural, perceptual-motor, and decisional tasks performed by EWOs are divided into several types of tasks. Procedural activities are subdivided into EW sensor management and countermeasures management, which includes use of chaff, electronic jammers, and flares. Perceptual-motor activities are subdivided into threat detection and identification, geographic threat orientation, countermeasures control and communication. Decisional activities include mission planning, threat assessment, response selection, and directional instruction. These tasks also include adjustments and checks on console equipment and employment of countermeasures through manual release mechanisms (procedural and psychomotor).

6.1 Perceptual-Motor Training Activities

Initial Training of EWOs consists of about 5 months of classroom instruction, simulator phases, and aircraft training at Mather AFB, California. The primary emphasis during this training is on signal detection, analysis, and identification of threats using generic tasks and equipment. Following initial training, the EWO is assigned to a specific type of aircraft at an operational unit, where he begins training to master the use of specific EW equipment for specific mission requirements. This training is accomplished during aircraft missions restricted to specific ranges. The nature of practice missions limits the fidelity and scope of the practice situation for EWOs, because there are no fully suitable training scenarios or methods available to simulate the conditions of combat in which multiple threats, weapons effects, and other complex environmental factors can be adequately experienced by the EWO. As a result, skill

development in novice EWOs and skill degradation in experienced EWOs and of major concern in training programs.

Although aircraft training presents less than an ideal training environment because of the difficulty of simulating threat characteristics and behavior, many elements of tasks can be practiced to a degree. Threat detection can be accomplished visually on scopes, or aurally. The combination of two sensory modes provides corollary inputs to assist in confirming threat identification. In some cases, early detection may be made only with aural information; however, most detection is made visually.

ALR-69 radar warning displays designate specific threats via digital read-outs. Ambiguities in signals may produce conflicting information which requires resolution by the human operator using previously anticipated threat information and/or using aural cues. Operator recall of signal characteristics such as pulse repetition frequency (PRF) and employment patterns is usually needed for positive signal identification. The read-outs are alphanumeric, each associated with a specific threat, and require memorization for spontaneous recall.

Relative threat orientation, as well as geographic threat orientation, is critical to aircraft safety during hostile area ingress. Awareness of the location of the threat relative to the aircraft is needed to provide relative bearing information, and to indicate whether range between the threat and the aircraft will increase (rear aspect), decrease (front aspect), or remain constant (right- or left-wing aspect). Orientation information is needed for the aircraft to evade detection and tracking, and to avoid entrance into the lock-on envelope of enemy radar. Depending upon the specific situation, low-level flight or egress from the threat area may be sufficient to avoid contact. However, timely and correct threat identification and orientation data are critical.

Initial training of EWOs includes types of threats such as air interceptors (AIs), surface-to-air missiles (SAMs), or anti-aircraft artillery (AAA), and appropriate countermeasure responses. At a higher order of cognitive activity, the operator must assess geographical location, relative bearing, type and mode of threat, and other related environmental and situational conditions in order to select and deploy appropriate countermeasures. The interaction of these factors increases the complexity of the decision-making task, the outcome of which is, of course, critical to the mission and crew.

6.2 Decisional Activities

The EWO performs a number of critical decision-making activities, primarily during the pre-mission and operational phases of aircraft deployment. During the pre-mission phase, planning requires intelligence information in order to plot known enemy radar emitters and associated weapon systems. Early detection and accurate signal identification are essential for proper threat assessment. Radar modes (search, track, or launch) are positive phase indications for detection and recognition of threats and for the employment of specific countermeasures. Responses by the EWO must be rapid and appropriate to the specific situational context. One response may be simply to maneuver the aircraft away from the threat. In this case, the EWO must provide an accurate roll-out heading for the pilot, using the relative bearing of the detected emission and the true bearing from the V-8 compass. The interpolation of the two information sources requires considerable training to produce adequate response latencies for correct roll-out headings, particularly for novice EWOs. This requirement appears to be suitable for automated response training to reduce cognitive load, and could be especially beneficial for transfer tasks such as multiple-threat encounters.

Threat assessment encompasses a variety of complex information factors, as indicated in Figure 2. Preliminary analysis (by the authors of the present report) from interviews with EWOs indicates expert EWOs acquire the capability to analyze threat factors in nearly simultaneous fashion, a skill which is obviously perfected through long-term practice (rehearsal of situations). Yet needed is in-depth analysis to ascertain (a) the specific subskills involved in this process, (b) the specific types of practice involved, and (c) the time required to reach task proficiency. Such data would be useful as a baseline for improving the training process using principles from cognitive task analysis to differentiate expert and novice skills and to derive improved training prescriptions.

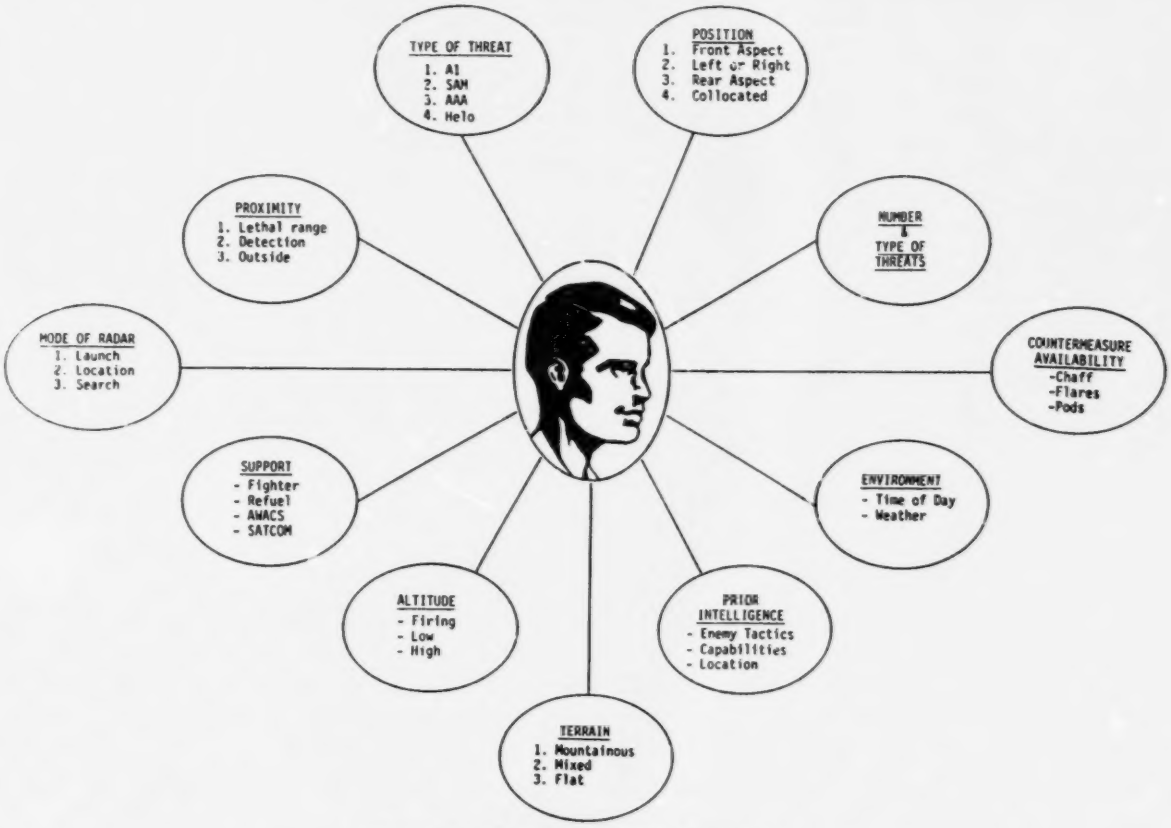

Figure 2. Threat Analysis Elements.

Based on preliminary analysis, cognitive approaches to analysis and design of training are indicated for the following areas of EWO training:

- symbolic interpretation of the ALR-69 system
- visual and aural identification of threats
- threat assessment (decision making) based on situational awareness
- selection and employment of countermeasures (decision making)

BEST COPY AVAILABLE

7.0 COGNITIVE-BASED INSTRUCTIONAL DESIGN

The literature in cognitive science and instructional design technology, reviewed in the preceding chapters, suggests many areas in which current training methodology can be improved to support the training of complex cognitive skills. These changes can and should be incorporated within the basic procedures of ISD design. The ISD model itself is atheoretic, offering a generic, systematized framework which establishes tasks for the instructional designer to perform in developing training programs. The critical stages of the ISD model requiring modification to incorporate cognitive procedures are the training analysis and design stages. The following sections discuss specific aspects of these modifications.

7.1 Analysis

Chapter 5 of this report defined cognitive task analysis, and contrasted it with the behavioral approach to task analysis embodied in current ISD procedures. Some of the issues involved in conducting a cognitive task analysis were also discussed.

There have been several recent attempts to conduct cognitive task analyses (e.g., Knerr et al., 1986; LRDC, 1986; Schvaneveldt, Goldsmith, Durso, Maxwell, Acosta, & Tucker, 1982; Thompson, Hopf-Weichel, & Geiselman, 1983). In each case, methods derived from cognitive science were used to evaluate knowledge-based organization for task performance. Furthermore, each cognitive task analysis was conducted either as a supplement to or as an alternative to traditional task analysis.

What is needed is an integrated task analysis methodology which (a) integrates methods and concepts from cognitive science with methods from traditional task analysis within the ISD framework, (b) can be followed by instructional designers who are practitioners rather than theoreticians or researchers, and (c) produces data in a form that is directly usable in prescriptive, cognitive-based instructional design formulas (see Section 7.2).

The outputs of the integrated task analysis should include the following:

1. Knowledge-base analysis
2. Mental model (novice and expert)
3. Task decomposition and component skill identification

Task decomposition corresponds most closely to current behavioral task analysis methodology. However, the criteria for skill categorization and task decomposition need to be modified to incorporate recent research findings on skill automatization (e.g., Myers & Fisk, 1985; Schneider & Fisk, 1982) and decision sequence analysis (Rasmussen, 1986).

The knowledge-base analysis and mental models would be new outputs of the training task analysis process. Currently, the skills and knowledge for each subtask or activity are identified, but without consideration of the interrelationships among the knowledge elements required for each component of a job, and without regard for how that knowledge develops over time.

The knowledge-base analysis should include identification of background knowledge (e.g., military science, enemy order of battle, basic radar principles) and domain-specific knowledge (concepts or entities, their features, and their interrelationships). It should include all the knowledge required for proficient performance, and should indicate core concepts and relationships and prototypical features as a basis for determining instructional sequencing.

A format for knowledge representation that is clear, easy to learn, and easy to understand must be developed or adapted. A number of methods have been developed and used in basic research in cognitive science, in work on expert systems, and in recent cognitive task analysis. Aspects of these methods are transferable to training analysis and design, under the guidance of the experienced cognitive analyst, and include the following:

1. Semantic networks
2. Production systems
3. GOMS (goals, operations, methods, selection rules)
4 Goal-directed representation (Woods & Hollnagel, 1987)
5. Task/action mapping models (Young, 1983)
6. Task performance network models (Knerr et al., in preparation)
7. Flow charts (e.g., Rasmussen, 1986)

A mental model for a task is an individual's representation or conceptualization of the task, methods for accomplishing the task, and how the knowledge domain operates relative to individual performance of the task. Mental models are evolving entities which an individual uses to interpret and respond to environmental events. What must be determined during task analyses is not the exact form of any one individual's mental model, but rather, generalized characteristics of mental models of novices and experts in the task. These can be used as a framework for teaching the task domain. The format of the model will vary depending on the domain but will, whenever possible, make use of graphic representations (e.g., maps, Venn diagrams, flowcharts) to aid comprehension and conceptualization (Woods, 1986) and permit analogies with known domains. Models will often represent various levels of abstraction (Hollan et al., 1984; Rasmussen, 1986).

A critical output from cognitive task analysis is the identification of components through systematic decomposition of the job or function. In this portion of the analysis, the job is first decomposed into skill-based tasks. These may or may not be behaviorally or temporally distinct. A detailed analysis of each task is then conducted. The form of this analysis will vary depending on the nature of the task and skills involved. For example, analysis of perceptual tasks might include a feature hierarchy, whereas analysis for complex problem-solving tasks would include a decision sequence analysis. Development of a skill-based task taxonomy can be used in part to derive training design decisions such as media selection, instructional sequencing, and identification of areas for automaticity training.

7.2 Design

Within the instructional design phase of ISD, four functional areas are specified: developing objectives, developing tests, describing entry behavior, and determining sequence and structure. The following sections describe how new methods from cognitive psychology can be incorporated within each functional area of the training design process.

7.2.1 Developing Objectives

This area concerns establishing the framework for curriculum development by stating learning objectives which bridge the gap between performing a task and learning how to perform a task.

BEST COPY AVAILABLE

Learning is the purpose of any instructional system, and objectives provide the structure. The terms "learning objectives," "instructional objectives," and "training objectives" are frequently used interchangeably.

The ISD model stresses specifically stated objectives. That is, learning objectives should specify actions, conditions, and standards for performance. Authorities have gone to great lengths in the ISD literature to describe methods and standards to be invoked in developing behavioral objectives as the foundation of the instructional development process. Yet, as precise as the specifications may appear, the language of such objectives is inadequate for cognitive skills. Mental or cognitive skills have proved much more difficult to describe and classify in the design context.

Bloom's Taxonomy of Educational Objectives (1956), a commonly used source for classifying objectives, offers some help in this regard. As a taxonomy, it is descriptive rather than prescriptive; however, it provides a more elaborate structure than does ISD for specifying cognitive skills. The six classification areas, in hierarchical order from low to high, are: knowledge, comprehension, application, analysis, synthesis, and evaluation. Bloom's work was directed primarily toward academic aspects of learning, and although useful to some degree for the present purposes of training analysis, more detailed elaboration of objectives is required for complex tasks involved in aircrew performance. The work of Bloom (1956) and Gagne (1977) is useful for explaining many aspects of mental skill development and for sequencing of instruction which is congruent with skill development theory. More recently, useful approaches have been developed for specifying designs or prescriptions for instruction/training.

Component Display Theory (Merrill, 1983) is an integrated, prescriptive framework which incorporates the work of such cognitive theorists as Bruner (1966) on alternative representations; Evans et al. (1962) on rule/example use; and Landa (1974) on algorithmization. Component Display Theory comes much closer than prior methodologies to providing an applied framework from which instructional designers can develop learning objectives using a cognitive emphasis.

Another significant approach useful for classification purposes is the distinction between skills suitable for automatic versus controlled processing. Skills involving consistently mapped components, as opposed to variably mapped components, may be candidates for the development of skill automaticity. Many of the procedural skills in aircrew tasks appear to be good candidates for automatization training, with the goal of "freeing" processing resources for other tasks requiring controlled processing. Considerable research is needed, however, to develop a reliable method for identifying specific types of skills for such training emphasis. Such skills should be identified as part of the learning objective specification during the training analysis process.

Recent research in metacognition is particularly applicable for higher-order cognitive skills such as those identified in Bloom's (1956) taxonomy--analysis, synthesis, and evaluation. The use of heuristics as applied to human problem solving has been a topic of considerable investigation, especially as related to differences between expert and novice performance. For example, Newell and Simon (1972) have provided a useful framework which includes identification of the problem space, and selection of operations to move from the initial state to the goal state. The ability to monitor one's own skills when performing a task would be a useful learning objective. Awareness of problem space and solution development would enhance individuals' ability to evaluate their own decisions (Collins & Smith, 1980; Edwards, 1968). The establishment of objectives which cover both behavioral and cognitive skills and provide prescriptions for instructional development are essential for updating the current ISD model. This need is particularly manifest for the complex skill requirements associated with modern weapon systems.

BEST COPY AVAILABLE

7.2.2 Developing Tests and Describing Entry Behavior

Tests provide significant information for the instructional developer in analyzing the effectiveness of instruction. They provide indications as to whether, and to what degree the specific learning objectives have been achieved. They can also serve to determine entry-level behaviors. Tests serve as points of reference prior to, during, and following the events of instruction.

Tests are used in military settings both to select and to classify personnel, as well as to determine their specific knowledges, abilities, aptitudes, and skills. Norm-referenced tests were first used on a large scale by the military to classify Infantry and Officer Candidate School nominees. It was not until the 1960's that criterion-referenced tests were introduced to determine mastery of instructional objectives. Criterion-referenced tests are well suited for measuring behaviorally anchored skills. For complex cognitive skills, however, domain-referenced tests provide a better indication of learner accomplishment.

Domain-referenced tests, which are based on knowledge domain specifications, describe the stimuli, the responses, and the scoring criteria to be used in determining the learner's achievement relative to knowledge and skill acquisition. Domain-referenced testing also enables the instructor to determine whether specific schemata, concepts, and/or heuristics have been developed by the learner. The use of such testing in conjunction with Component Display Theory provides a reliable means of demonstrating the acquisition of facts, concepts, principles, or procedures (Merrill, 1983). The development of domain-specific tests provides the means of validating the acquisition of information, and to some extent helps define approaches to the design or structure of the instructional process. Microcomputer applications have also served to expand the role of testing by including provisions for automated feedback, remedial cues, and analysis of learner performance as integral components of instructional design. The advent of the microcomputer has stimulated increased awareness of the instructional process and has focused demand for quality training products and software. As an outgrowth of research on computer-aided instruction, some additional perspectives on testing for cognitive learning objectives have emerged. Knerr, Nadler, and Dowell (1984) developed a system of instructional algorithms, called the Training Effectiveness and Cost Effectiveness Prediction (TECEP) method, which are matched to specific types of learning tasks. TECEP, in some respects, represents the beginning of a bridging technology between cognitive task analysis and ISD. Sticha, Blacksten, Knerr, Morrison, and Cross (1986) developed a method for optimizing the design of simulation-based training systems (OSBATS), which provides a methodology for determining training system requirements using inputs from cognitive task analysis. Criterion-referenced and domain-referenced testing theory is consistent with these design methods.

7.2.3 Determining Sequence and Structure

Methodology for the sequencing of instructional objectives is supported by educational and psychological literature. Sequencing of cognitive learning objectives requires a somewhat different approach than sequencing of behavioral objectives as practiced in ISD. The sequencing issue is very often a function of close integration of the analytical and delivery phases of instruction. For example, for development of skill automaticity, determination of optimal sequencing of training is dependent upon differentiation and classification of task components by types. Bruner (1966) made a key point of organizing curriculum content so that knowledge can be retrieved, manipulated, and applied. Bruner's model indicates that knowledge can be represented in these three modes: (a) by a set of actions appropriate for achieving a certain result (enactive representation), (b) by a set of summary images or graphics that stand for a concept without defining it fully (iconic representation), and by a set of symbolic or logical propositions drawn from a symbolic system that is governed by rules or laws for forming and

transforming propositions (symbolic representation). The sequence in which these modes are introduced and used depends upon the goals of instruction, the course content, and the capabilities of learners. This is somewhat akin to the approach posited by Gagne (1970) and Gagne and Briggs (1974), which suggests a progressive sequencing of training based upon the nature and complexity of the component skills that make up the task. Other researchers (e.g., Anderson, 1981; Bonner et al., 1986; Fitts, 1964) have offered a number of structural and sequencing approaches which could potentially improve ISD procedures if validated and integrated properly. To achieve such integration would require a research effort of considerable magnitude. Any approach based upon such theory or combinations of theories must be subjected to adequate test and validation in suitably representative applied settings.

8.0 CONCLUSIONS

The present effort reviewed recent work in cognitive science and instructional technology to provide a foundation for developing cognitive-based instruction for Air Force aircrew training program development applications. The premise upon which this work was undertaken was that current training design and development methods are scientifically inadequate to address the training of complex cognitive tasks that comprise aircraft missions. This chapter summarizes the findings of this effort, and Appendix A presents an overview of follow-on work required to more fully exploit the development of cognitive concepts for aircrew training analysis and design applications.

Several advances in cognitive science reviewed in this report provide new ways of characterizing learning and skill development which have important implications for instructional design and development. These advances suggest approaches that are more appropriate for the complex cognitive tasks which comprise aircrew missions than are the behavioral analytical procedures which characterize the current ISD process. These cognitive constructs deal with how information is processed and organized in memory, how processing resources are allocated, and how skills develop. Thus, in regard to the instructional systems development process, the cognitive approach implies that training should focus on knowledge development and structure learning activities in a way that facilitates that development.

The work reviewed on knowledge representation and schema development has direct implications for training design. The theory that schemata are stored as prototypical concepts implies that typical or basic instances of a concept should be presented to the learner first. The extension and application of this theory are seen in the Elaboration Theory of Instruction (Reigeluth & Stein, 1983). Several task analysis methods have been demonstrated which appear to be effective in getting at the nature and organization of stored knowledge. These techniques also offer potential for the design of training materials and activities. Following directly from the research on knowledge representation is the concept of mental models, a subset of an individual's knowledge that influences his/her performance of a task. A number of instructional techniques can be used to encourage the development and efficient use of mental models in learning and performance.

The work of Anderson (1982) and Rasmussen (1986), among others cited in this report, has implications for skills development, including the role and timing of practice and the development of automaticity. Research on skill automaticity and the conditions for its development cited in this report suggests ways in which tasks can be broken down into components to facilitate skill automaticity.

Research on metacognition can also contribute much to training development. Learning strategies and problem-solving skills can be taught directly as part of any training program. In addition, courses can be structured using proper sequencing, instructions, feedback, and test

questions to encourage the development of good metacognitive skills. Research has also shown the importance of self-monitoring and self-regulation in learning and performance, and these skills can be communicated to students.

Although current approaches to training have a strong behavioral bias, there have been some recent attempts to incorporate cognitive concepts in instructional design. One example is the Elaboration Theory, previously discussed. Practical approaches for specific training application can be derived from this theoretical work.

Behavioral analytical techniques have been demonstrated to be inadequate for purposes of developing training for higher-order mental skills. Task-analytic techniques for deriving the mental organization of information can be used to improve design shortfalls in the ISD process. Techniques such as the ordered tree method developed by Naveh-Benjamin et al. (1986) appear promising in this regard. Further, commonly used analytical techniques such as structured interviews and protocol analysis can be modified/amplified to derive knowledge structure and mental models. Computer-based performance modeling techniques are another fertile area for systematic analysis, and offer the potential for elaborate modeling of the human-machine interface as a means for representing knowledge structure in a real-time or dynamic mode.

New methods from cognitive science such as these can be combined with traditional task analysis methods to derive integrated analytical approaches for all types of training tasks. Many aspects of the ISD model, including the basic structure of the instructional process, are valid and constitute an effective way to approach training development. Critical stages of the model which will benefit from cognitive methodology are the analytical and design stages. Based upon our review of recent research in cognitive science and instructional design, we have suggested ways to improve each area.

What would a cognitive approach add to the current ISD model? It would support the development of training programs which build a flexible, accessible knowledge base and efficient mental models for understanding of the task and its performance. Through this approach, the objective would be to provide the trainee with the underpinnings of skill development required to master complex cognitive skills, rather than merely learning to accomplish sequences of procedural steps. In addition, it seems apparent that cognitive methodology can greatly facilitate transfer of training by teaching metacognitive skills as strategies for improved learning and performance.

REFERENCES

Adams, L.T., Perfutto, G.A., Yearwood, A., Kasserman, J., Bransford, J.D., & Franks, J.J. (1985). Facilitating access. Unpublished manuscript, Vanderbilt University, Nashville, TN.

Anderson, J.R. (1976). Language, memory and thought. Hillsdale, NJ: Erlbaum.

Anderson, J.R. (1981). Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum.

Anderson, J.R. (1982). Acquisition of cognitive skill. Psychological Review, 89, 369-406.

Anderson, R.C., Spiro, R., & Montague, W.E. (Eds.). (1977). Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum.

Atwood, M.E., & Polson, P.G. (1976). A process model for the water jar problems. Cognitive Psychology, 8, 191-216.

Ausubel, D.P. (1960). The use of advance organizers in learning and retention of meaningful verbal material. Journal of Educational Psychology, 51, 267-272.

Belmont, J., & Butterfield, E. (1977). The instructional approval of developmental cognitive research. In R. Keil & J. Hagan (Eds.), Perspectives on the development of memory and cognition. Hillsdale, NJ: Erlbaum.

Bender, T.A. (1986). Monitoring and the transfer of individual problem solving. Contemporary Educational Psychology, 11, 161-169.

Bereiter, C., & Scardamalia, M. (1985). Cognitive coping strategies and the problem of "inert" knowledge. In S. Chipman, J.W. Segal, & R. Glaser (Eds.), Thinking and learning skills: Current research and open questions (Vol. 2, pp. 65-80). Hillsdale, NJ: Erlbaum.

Bernascoli, A. (1987). Can students' performance on an interactive design task improve with instructions? Unpublished master's thesis, Lehigh University, Bethlehem, PA.

Bloom, B.S. (Ed.). (1956). Handbook I: Cognitive domain. In Taxonomy of educational objectives: The classification of educational goals. New York: Longman.

Bobrow, D.G., & Norman, D.A. (1975). Some principles of memory schemata. In D.G. Bobrow & A.M. Collins (Eds.), Representation and understanding: Studies in cognitive science. New York: Academic Press.

Bonner, J., Collins, A., Eggan, G., Fredericksen, J., Hamilton, R., Harris, C., Knerr, M., Lesgold, A., Massey, D., Means, B., Roth, C., & White, B. (1986). Development of an integrated system to assess and enhance basic job skills: Training specifications and prototypes subsystem plan (HumRRO Interim Draft Report). Alexandria, VA: Human Resources Research Organization.

Bransford, J.D., Nitsch, K.E., & Franks, J.J. (1977). Schooling and the facilitation of knowledge. In R.C. Anderson, R.J. Spiro, & W.E. Montague (Eds.), Schooling and the acquisition of knowledge (pp. 31-56). Hillsdale, NJ: Erlbaum.

Bransford, J., Sherwood, R., Nye N., & Rieser, J. (1986). Teaching thinking and problem solving. American Psycho[illegible], 41(10), 1078-1089.

Brown, A.L., Campione, J.C., & Day, J.D. (1981). Learning to learn: On training students to learn from texts. Educational Researcher, 10, 14-21.

Bruner, J.S. (1966). Toward a theory of instruction. New York: Norton.

Carey, S. (1986). Cognitive science and science education. American Psychologist, 41, 1123-1130.

Chase, W.G., & Simon, H.A. (1973). The mind's eye in chess. In W.G. Chase (Ed.), Visual information processing (pp. 215-281). New York: Academic Press.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Chomsky, A.N. (1957). Syntactic structures. The Hague: Mouton.

Colle, H.A., & DeMaio, J. (1978). Measurement of attentional capacity load using dual-task performance operating curves (AFHRL-TR-78-5, AD-A055 690). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

Collins, A.M., & Loftus, E.F.A. (1975). Spreading activation theory of semantic processing. Psychological Review, 82, 407-428.

Collins, A., & Smith, E.E. (1980). Teaching the process of reading comprehension (Tech. Rep. No. 182). Cambridge, MA: Bolt, Beranek and Newman, Inc.

Dansereau, D. (1978). The development of a learning strategies curriculum. In H.F. O'Neil, Jr. (Ed.), Learning strategies (pp. 1-29). New York: Academic Press.

DeCorte, E., & Verschaffel, L. (1981). Children's solution process in elementary arithmetic problems: Analysis and improvement. Journal of Educational Psychology, 73, 765-779.

DeGroot, A.B. (1966). Thought and choice in chess. The Hague: Mouton.

DeJong, T., & Ferguson-Hessler, M.G. (1986). Cognitive structures of good and poor novice problem solvers in physics. Journal of Educational Psychology, 78, 279-288.

DeKleer, J., & Brown, J.S. (1981). Mental models of physical mechanisms and their acquisition. In J.R. Anderson (Ed.), Cognitive skills and their acquisition (pp. 285-309). Hillsdale, NJ: Erlbaum.

Department of the Air Force. (1986, July). Instructional systems development (AFM-50-2). Washington, DC.

Department of the Air Force. (1978, July). Handbook for designers of instructional systems (AFP 50-58). Washington, DC.

Derry, S.J., & Murphy, D.A. (1986). Designing systems that train learning ability: From theory to practice. Review of Educational Research, 56(1), 1-39.

diSessa, A.A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. Cognitive Science, 6, 37-75.

Eberts, R., & Schneider, W. (1985). Internalizing the system dynamics for a second-order system. Human Factors, 27(4), 371-393.

Edwards, W. (1968). Conservatism in human information processing. In B. Kleinmuntz (Ed.), Formal representation of human judgement. New York: Wiley.

Elstein, A.S., Shulman, L.S., & Sprafka, S.A. (1978). Medical problem solving. Cambridge, MA: Harvard University Press.

Evans, J.L., Homme, L.E., & Glaser, R. (1962). The RULEG system for the construction of programmed verbal learning sequences. Journal of Educational Research, 55, 513-518.

Farr, M.J. (1986). The long-term retention of knowledge and skills: A cognitive and instructional perspective (Final Report M-205). Alexandria, VA: Institute for Defense Analysis.

Federico, P.A. (1983). Changes in the cognitive components of achievement as students proceed through computer-managed instruction. Journal of Computer-Based Instruction, 9, 156-168.

Federico, P.A., & Landis, D.B. (1979). Predicting student performance in a computer-managed course using measures of cognitive styles, abilities, and aptitudes (Tech. Rep. NPRDC-TR-79-30). San Diego, CA: Navy Personnel Research and Development Center.

Federico, P.A., & Landis, D.B. (1980). Relationships among selected measures of cognitive style, abilities, and aptitudes (Tech. Rep. NPRDC-TR-80-23). San Diego, CA: Navy Personnel Research and Development Center.

Fisk, A.D. (1985). Automatic and controlled processing approach to interpreting vigilance performance. Paper presented at the 29th Annual Meeting of the Human Factors Society, Baltimore, Maryland.

Fisk, A.D., Ackerman, P., & Schneider, W. (1985). Automatic and controlled information processing in human factors. In P.A. Hancock (Ed.), Human Factors Psychology. New York: North Holland.

Fisk, A.D., & Schneider, W. (1981). Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. Human Factors, 23(6), 737-750.

Fisk, A.D., & Schneider, W. (1983). Category and work search: Generalizing search principles to complex processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9, 177-195.

Fitts, P.M. (1964). Perceptual-motor learning. In A.W. Melton (Ed.), Categories of Human Learning. New York: Academic Press.

Flavell, J.H. (1979). Metacognition and cognitive monitoring. American Psychologist, 34(10), 906-911.

Flower, L.S., & Hayes, J.R. (1980). The dynamics of composing: Making and juggling constraints. In L. Gregg & E. Stein (Eds.), Cognitive processes in writing: An interdisciplinary approach (pp. 31-50). Hillsdale, NJ: Erlbaum.

Gagne, R.M. (1965). The conditions of learning. New York: Holt, Rinehart, and Winston.

Gagne, R.M. (1970). The conditions of learning (2nd ed.). New York: Holt, Rinehart, and Winston.

Gagne, R.M. (1977). The conditions of learning (3rd ed.). New York: Holt, Rinehart, and Winston.

Gagne, R.M, & Briggs, L. (1974). Principles of instructional design. New York: Holt, Rinehart, and Winston.

Gagne, R.M., & Glaser, R. (1987) Foundations in learning research. In R. Glaser (Ed.), Instructional techniques: Foundations (pp. 49-83). Hillsdale, NJ: Erlbaum.

Gallini, J.K., & Fisk, A.D. (1986). An information processing approach to instructional systems design. Educational Technology, Vol XXVI, 24-26.

Gelman, H. (1986). Some trends in the study of cognition. In S. Koch & D. Leary (Eds.), A century of psychology as a science, 420-437.

Gick, M.L., & Holyoak, K. (1980). Analogical problem solving. Cognitive Psychology, 12, 306-355.

Glaser, R. (1976). Cognitive psychology and instructional design. In D. Klahr (Ed.), Cognition and instruction. New York: Wiley.

Glaser, R. (1984). Education and thinking: The role of knowledge. American Psychologist, 39(2), 93-104.

Glaser, R., Pelligrino, J.W., & Lesgold, A.M. (1978). Some directions for a cognitive psychology of instruction. In A.M. Lesgold & J.W. Pelligrino (Eds.), Cognitive psychology and instruction. New York: Plenum.

Greeno, J.G. (1978). Nature of problem solving abilities. In W.K. Estes (Ed.), Handbook of learning and cognitive processes (Vol. 5). Hillsdale, NJ: Erlbaum.

Halff, H.M., Hollan, J.D., & Hutchins, E.L. (1986). Cognitive science and military training. American Psychologist, 41(10), 1131-1139.

Hasher, L., & Zachs, R.T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356-388.

Hayes, J.R., & Simon, H.A. (1976). The understanding process: Problem isomorphs. Cognitive Psychology, 8, 165-190.

Hirst, W., Spelker, E.S., Reeves, C.C., Caharach, G., & Neisser, U. (1980). Dividing attention without alternation or automaticity. Journal of Experimental Psychology: General, 109, 98-117.

Hoko, J.A. (1986) What is the scientific value of comparing automated and human instruction? Educational Technology, 16(19).

Hollan, J.D., Hutchins, E.L., & Weitzman, L. (1984). STEAMER: An information processing analysis of a routine cognitive skill. Cognitive Psychology, 12, 32-74.

Horton, M.S., & Markman, E.M. (1980). Development differences in the acquisition of basic and superordinate categories. Child Development, 51, 708-719.

Johnson, P.E. (1967). Some psychological aspects of subject-matter structure. Journal of Educational Psychology, 60, 32-40.

Kahnemann, D., & Tversky, A. (1972). Subjective probability: A judgement of representativeness. Cognitive Psychology, 3, 430-454.

Kiewra, K.A., & Frank, B.M. (1986). Cognitive style: Effects of structure at acquisition and testing. Contemporary Educational Psychology, 11, 253-263.

Knerr, C.M., Morrrison, J.E., Mumaw, R.J., Sticha, P.J., Blacksten, H.R., & Harris, C. (in preparation). Analysis and design of part-task training for aircrew skills. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Knerr, C.M., Morrison, J.E., Mumaw, R.J., Stein, D.J., Sticha, P.J., Hoffman, R.G., Buede, D.M., & Holding, D.H. (1986). Simulation-based research in part-task training (AFHRL-TR-86-12, AD-B107 293L). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Knerr, C.M., Nadler, L.B., & Dowell, S.K. (1984). Training transfer and effectiveness models (Final Report FR-TRD (VA)-84-1). Alexandria, VA: Human Resources Research Organization.

Kulik, J.A., Bangert, R.L., & Williams, G.W. (1983). Effects of computer-based teachings on secondary school students. Journal of Educational Psychology, 75(1), 19-26.

Landa, L. (1974). Algorithmization in learning and instruction. Englewood Cliffs, NJ: Educational Technology.

Larkin, J.H. (1979). Processing information for effective problem solving. Engineering Education, 285-288.

Learning Research and Development Center. (1986). Cognitive task analysis to enhance technical skills training and assessment. Pittsburgh: University of Pittsburgh.

Long, G.M. (1975). Rod and frame performance among naval aviation personnel. Perceptual and Motor Skills, 41, 950.

Mayer, R.E. (1981). The psychology of how novices learn computer programming. Computing Surveys, 13, 121-141.

McDonnell Douglas Astronautics Company. (1986). Instructional Support Software System (AFHRL-TR-85-53, AD-A166 776). Lowry AFB, CO: Training Systems Division, Air Force Human Resources Laboratory.

Meichenbaum, D. (1985). Teaching thinking: A cognitive-behavioral perspective. In S.F. Chipman, J.W. Segal, & R. Glaser (Eds.), Thinking and learning skills: Research and open questions (Vol. 2). Hillsdale, NJ: Erlbaum.

Merrill, M.D. (1983). Component display theory. In C.M. Reigeluth (Ed.), Instructional design theories and models: An overview of their current status. Hillsdale, NJ: Erlbaum.

Merrill, M.D., Richards, R.E., Schmidt, R.V., & Wood, N.D. (1977). Interim training manual for the instructional strategy diagnostic profile (NPRDC Special Report 77-14). San Diego, CA: Navy Personnel Research and Development Center.

Mervis, C., & Crisafi, M. (1982). Order of acquisition of subordinate, basic and superordinate level categories. Child Development, 53, 258-266.

Mervis, C., & Pani, J. (1980). Acquisition of basic object categories. Cognitive Psychology, 12, 496-522.

Messick, S. (1984). The nature of cognitive styles: Problems and promise in educational practice. Educational Psychologist, 19(2), 59-74.

Miller, E.E. (1975). Instructional strategies using low-cost simulation for electronic maintenance (HumRRO Tech. Rep. FR-WD (TX)-75-20). Alexandria, VA: Human Resources Research Organization.

Minsky, M.A. (1975). A framework for representing knowledge. In P. Winston (Ed.), The psychology of computer vision. New York: McGraw-Hill.

Montague, W.E., Ellis, J.A., & Wulfeck, W.H. (1983). The instructional quality inventory (IQI): A formative evaluation tool for instructional systems development (NPRDC-TR-83-31). San Diego, CA: Navy Personnel Research and Development Center.

Morris, N.M., & Rouse, W.B. (1985). Review and evaluation of empirical research in troubleshooting. Human Factors, 27(5), 503-530.

Myers, G.L., & Fisk, A.D. (1985). Toward a skill-based training technology: Review, evaluation and application of automatic/controlled processing training guidelines. Proceedings of the 29th Annual Meeting of the Human Factors Society, Baltimore, Maryland.

Naveh-Benjamin, M., McKeachie, W.J., Lin, Y., & Tucker, D.G. (1986). Inferring students' cognitive structures and their development using the "ordered tree technique." Journal of Educational Psychology, 78(2), 130-140.

Newell, A., Shaw, J.C., & Simon, H.A. (1985). Elements of a theory of human problem solving. Psychological Review, 65, 151-166.

Newell, A., & Simon, M.A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Norman, D.A., Gentner, D.R., & Stevens, A.L. (1976). Comments on learning schemata and memory representation. In D. Klahr (Ed.), Cognition and instruction. Hillsdale, NJ: Erlbaum.

O'Neil, H.F., Jr. (Ed.). (1978). Learning strategies. New York: Academic Press.

O'Neil, H.F., Jr., & Spielberger, C.D. (Eds.). (1979). Cognitive and affective learning strategies. New York: Academic Press.

Orlansky, J., & String, J. (1979). Cost-effectiveness of computer-based instruction in military training (IDA Paper P-1375). Arlington, VA: Institute of Defense Analysis.

Pask, G., & Scott, B.C.E. (1972). Learning strategies and individual competence. International Journal of Man-Machine Studies, 4, 217-253.

Pelligrino, J.W. (1985). Inductive reasoning ability. In R.J. Sternberg (Ed.), Human abilities: An information-processing approach (pp. 195-225). New York: W.H. Freeman.

Perfutto, G.A., Bransford, J.D., & Franks, J.J. (1983). Constraints on access in a problem solving context. Memory and Cognition, 11, 24-31.

Piaget, J. (1952). The relation of affectivity to intelligence in the mental development of the child. Bulletin of Menninger Clinic, 26, 129-137.

Piaget, J. (1954). The construction of reality in the child. New York: Basic.

Posner, M.I., & Snyder, C.R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), Information processing and cognition: The Loyola Symposium. Hillsdale, NJ: Erlbaum.

Rasmussen, J. (1983). Skills, rules, knowledge: Signal, signs, symbols and other distinctions in human performance models. IEEE Transportation System-Man Cybernetics, SMC-13(3), 257-267.

Rasmussen, J. (1986). Information processing and human-machine interaction: An approach to cognitive engineering. New York: North Holland.

Redding, R.E. (1986). Future directions in the study of Metacognition: Implications for educational practice. Unpublished manuscript, Lehigh University, Bethlehem, PA.

Reed, S.K. (1972). Cognition: Theory and application. Monterey, CA: Brooks/Cole.

Reed, S.K., Ernst, G.W., & Banerji, R. (1974). The role of analogy in transfer between similar problem states. Cognitive Psychology, 6, 436-450.

Reed, S.K., & Johnson, J.A. (1977). Memory for problem solutions. In G.H. Bower (Ed.), The Psychology of learning and motivation (Vol. II). New York: Academic Press.

Reigeluth, C.M., & Stein, F.S. (1983). The elaboration theory of instruction. In C.M. Reigeluth (Ed.), Instructional design theories and models: An overview of their current status. Hillsdale, NJ: Erlbaum.

Romiszowski, A.J. (1981). Designing instructional systems: Decision-making in course planning and curriculum design. New York: Nichols.

Rosch, E., & Mervis, C. (1975). Family resemblances: Studies in the internal structure of categories. Cognitive Psychology, 7, 573-605.

Rosch, E., Mervis, C., Gray, W., Johnson, D., & Boyes-Braen, P. (1976). Objects in categories. Cognitive Psychology, 8, 382-439.

Roscoe, S.N., Jensen, R.S., & Gawron, V.J. (1980). Introduction to training systems. In S.N. Roscoe (Ed.), Aviation psychology. Ames, IA: Iowa State.

Rumelhart, D.E., & Norman, D.A. (1981). Analogical processes in learning. In J.R. Anderson (Ed.), Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum

Rumelhart, D.E., & Norman, D.A. (1983). Representation in memory (DNR 8302). La Jolla, CA: University of California, San Diego, Center for Human Information Processing.

Rumelhart, D.E., & Ortony, A. (1979). The representation of knowledge in memory. In R.C. Anderson et al. (Eds.), Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum.

Scardamalia, M., & Bereiter, C. (1985). Fostering the development of self-regulation in children's knowledge processsing. In S.F. Chipman, J.W. Segal, & R. Glaser (Eds.), Thinking and learning skills: Research and open questions (Vol. 2). Hillsdale, NJ: Erlbaum.

Schneider, W. (1985). Training high-performance skills: Fallacies and guidelines. Human Factors, 27(3), 285-300.

Schneider, W., & Fisk, A.D. (1982) Degree of consistent training: Improvements in search performance and automatic process development. Perception and Psychophysics, 31, 160-168.

Schneider, W., & Shiffrin, R. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 84, 1-66.

Schneider, W., & Shiffrin, R. (1985) Categorization (restructuring) and automatization: Two separate factors. Psychological Review, 92(3), 424-428.

Schoenfeld, A.H. (1979). Explicit heuristic training as a variable in problem-solving performances. Journal of Research in Mathematics Education, 10, 173-187.

Schoenfeld, A. (1982). Measures of problem-solving performance and of problem-solving instruction. Journal for Research in Mathematics Education, 13, 31-49.

Schoenfeld, A. (1983). Episodes and executive decisions in mathematical problem solving. In H.P. Ginsberg (Ed.), The development of mathematical thinking (pp. 345-395). New York: Academic Press.

Schoenfeld, A. (1985). Mathematical problem solving. New York: Academic Press.

Scholnick, E.K. (Ed.). (1983). New trends in conceptual representation: Challenges to Piaget's theory? Hillsdale, NJ: Erlbaum.

Schvaneveldt, R.W., Goldsmith, T.E., Durso, F.T., Maxwell, K., Acosta, H.M., & Tucker, R.G. (1982). Structures of memory for critical flight information (AFHRL-TP-81-46, AD-A116 510) Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Shavelson, R.S., & Stanton, G.C. (1975). Concept validation: Methodology and application to three measures of cognitive structure. Journal of Educational Measurement, 12, 67-85.

Shepherd, A., Marshall, E.C., Turner, A., & Duncan, K.D. (1977). Diagnosis of plant failures from a control panel: A comparison of three training methods. Ergonomics, 20, 347-361.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Siegler, R. (1981). Developmental sequences within and between concepts. Monographs of the Society for Research in Child Development, 46(2, Serial No. 189).

Silver, E.A. (1981). Recall of mathematical problem information: Solving related problems. Journal of Research in Mathematics Education, 12, 54-64.

Smith, E.E., Adams, N., & Schorr, D. (1978). Fact retrieval and the paradox of interface. Cognitive Psychology, 10, 438-464.

Snelbecker, G.E. (1985). Learning theory, instructional theory, and psycho-educational design. Latham, MD: University Press.

Spears, W.D. (1983). Processes of skill performance: A foundation for the design and use of training equipment (NAVTRAEQUIPCEN 78-C-0113-4). Orlando, FL: Naval Training Equipment Center.

Sticha, P.J., Blacksten, H.R., Knerr, C.M., Morrison, J.E., & Cross, K.D. (1986). Optimization of simulation-based training systems (Final Report 86-13). Alexandria, VA: Human Resources Research Organization.

Thompson, J.R., Hopf-Weickel, R., & Geiselman, R.E. (1983). The cognitive bases of intelligence analysis (Prepared for US Army Research Institute for the Behavioral and Social Sciences). Woodland Hills, CA: Operating Systems Division, LOGICON.

Thorndyke, P., & Hayes-Roth, F. (1979). The use of schemata in the acquisition and transfer of knowledge. Cognitive Psychology, 11, 82-106.

Thorndyke, P., & Yekovich, F. (1980). A critique of schema-based theories of human story memory. Poetics, 9, 23-49.

Tuthill, D., & Ashton, P. (1983). Improving educational research through the development of educational paradigms. Educational Researcher, 12(10), 6-14.

Tversky, A., & Kahnemann, D. (1973). Availability: A heuristic for judging frequency and probability. Cognitive Psychology, 8, 165-190.

Warm, J.S., Dember, W.N., Lazetta, T.M., Bowers, J.C., & Lysaght, R.J. (1985). Information processing in vigilance performance: Complexity revisited. Paper presented at the 29th Annual Meeting of the Human Factors Society, Baltimore, Maryland.

Weinstein, C.E., Underwood, V.L., Wicker, F.W., & Cubberly, W.E. (1979). Cognitive learning strategies: Verbal and imaginal elaboration. In H.F. O'Neil & C.D. Spielberger (Eds.), Cognitive and affective learning strategies (pp. 45-75). New York: Academic Press.

Wetzel, S.K., Knoske, P.J., & Montague, W.E. (1983). Quality assessment of a navy operator training course (NPRDC Special Report 83-53). San Diego, CA: Navy Personnel Research and Development Center.

Wickens, C.D. (1984). Engineering psychology and human performance. Columbus, OH: Charles E. Merril.

Wong, B.Y.L. (1980). Activating the inactive learner: Use of questions/prompts to enhance comprehension and retention of implied information in learning disabled children. Learning Disability Quarterly, 3, 29-37.

Wong, B.Y.L. (1982). Metacognitive and learning disabilities. Topics in Learning and Learning Disabilities, 2(1).

Wong, B.Y.L., & Swatsky, D. (1984). Sentence elaboration and retention of good, average, and poor readers. Learning Disabilities Quarterly, 7, 229-236.

Woods, D.D. (1986). Paradigms for intelligent decision support. In E. Hollnagel, G. Mancini, & D.D. Woods (Eds.), Intelligent decision support in process environments. Berlin: Springer-Verlaz.

Woods, D.D., & Hollnagel, E. (in press). Mapping cognitive demands in complex problem solving worlds. International Journal of Man Machine Studies.

Young, R.M. (1983). Surrogates and mappings: Two kinds of conceptual models for interactive devices. In G. Gentner & A.L. Stevens (Eds.), Mental models. Hillsdale, NJ: Erlbaum.

APPENDIX A: PROPOSED FOLLOW-ON WORK

The overall goal of the proposed follow-on to the present literature review is to develop and validate an integrated task analysis methodology which incorporates cognitive concepts within the existing ISD framework. As discussed in Chapter 7, the analytical aspects of the ISD process require updating in order to facilitate design and development strategies for higher-order cognitive skill training systems. The proposed methodology will incorporate the cognitive concepts and methods reviewed in the present report to provide an integrated methodology within the basic structure of ISD procedures.

To develop and validate such an integration, four specific technical objectives are required:

1. Develop a handbook describing the integrated task analysis methodology.

2. Complete basic EW task analysis based on EWO requirements for MC-130 operations.

3. Extend EW task analysis to a second site, using methods developed in Objective 1 above as a means to test and refine the methodology.

4. Develop a training program for one aspect of EW tactics to support implementation of analysis in Objective 3 and methodology in Objective 1.

5. Revise the handbook developed in Objective 1 to incorporate lessons learned from work accomplished in meeting the requirements for objectives 1-4.

Objective 1 is primary, to develop the handbook; the other objectives support the first. The proposed handbook would be directed principally toward the instructional designer and would contain detailed cognitive methodology, with procedures for integrating this methodology within the ISD framework. It would contain procedures for knowledge-base analysis, determination of mental models for novice and expert task performance, and task decomposition and component skill identification. It would also include methods for gathering and analyzing task data to derive the necessary information. Methods would include interviews, questionnaires, and observations--as are currently used--and methods from cognitive science for knowledge-base analysis (e.g., Naveh-Benjamin et al., 1986; Shavelson & Stanton, 1975). In addition to describing procedures, the handbook would include the rationale for the methodology and complete research references.

The second objective is to complete the basic EW task analysis guided by cognitive concepts that was begun in the present effort. The purpose of this analysis is to determine the cognitive components of a specific EW job and to evaluate alternative methods of analysis. This analysis was begun and initial results are reported in the present report.

This analysis would serve a secondary purpose in providing inputs for courseware design which can be implemented on a part-task trainer, for example.

Thus far, our analysis indicates that the training of EW skills is one area that would significantly benefit from the cognitive approach. EWOs perform a number of critical perceptual and decisional activities during the pre-mission and operational phases of aircraft deployment. These activities include visual and aural identification of threats; threat assessment taking into account relative threat orientation, geographic threat orientation, type and mode of radar, environment factors and mission factors, and countermeasures selection based on threat assessment, countermeasures availability, understanding of countermeasure effects, and potential enemy responses.

The EWO's job involves many cognitive aspects--a complex knowledge base and decision making based on a number of factors. However, the complexity of the job depends on the EW mission of the aircraft involved. The EW mission of the MC-130 is a defensive one, involving a small set of countermeasures and limited tactics; thus, it is less complex than many EWO missions. This led us to propose the third objective.

The third technical objective is to extend the EW task analysis to a second site (to be determined) with a more complex EW mission. This analysis would be conducted after an initial draft of the integrated task analysis methodology handbook has been developed. It would be carried out by following the procedures developed, as a means to test and refine the methodology.

The reasons for extending the task analysis are threefold. First, it would allow the development of a more generalized model of EW tactics, less concerned with aircraft-specific aspects of the EW job. Second, for a site with a more complex EW mission, the cognitive processing load and complexity will be greater, and more analysis will be needed. Third, a second analysis will allow us to evaluate the usefulness of the methodology and determine how it can be improved.

The major test of the integrated task analysis methodology is determining whether it results in an improved training program. Therefore, a fourth objective is to select one aspect of EW tactics training that would benefit from cognitive-based training and develop a training program. The training program would be implemented on a general-purpose microcomputer system with commercially available hardware and software components. A field evaluation of the program would be conducted to determine its value in improving performance in the selected skill.

The low-cost trainer would provide a convenient environment that could be easily adapted for the training of other cognitive skills. Part-task trainers are well suited to cognitive skill training because the full fidelity of the task environment is less important than representing the conceptual aspects of the task. Further, practice can be concentrated on conceptually difficult aspects of the job as a supplement to ongoing training or as pre-training.

A cognitive approach to task analysis and training design developed in a follow-on effort would have wide applicability. A few examples which illustrate the breadth of tasks within aircrew training likely to benefit from the application of analysis and design for higher-order cognitive skills are as follows:

1. Intelligence analysis and mission planning
2. Sensor data interpretation and evaluation
3. Emergency procedures
4. Combat tactics
5. Situation awareness

Task analysis is the primary tool for developing training programs, designing human-machine systems or user-computer interfaces, and developing knowledge bases for expert systems or intelligent decision support systems. The development of improved methodologies for conducting task analyses could have application in all such design aspects. In summary, cognitive-based integrated task analysis can benefit many areas of aircrew training. However, the required next step is to extend germane theory into applied training development problems in order to demonstrate how the gap between training theory and practice can be bridged to the benefit of Air Force aircrew training programs.

* U. S. GOVERNMENT PRINTING OFFICE: 1988 - 561048 / 80025